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High Frequency/Automatic Link Establishment (HF/ALE) Radio Propagation Test to Antarctica

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PREFACE

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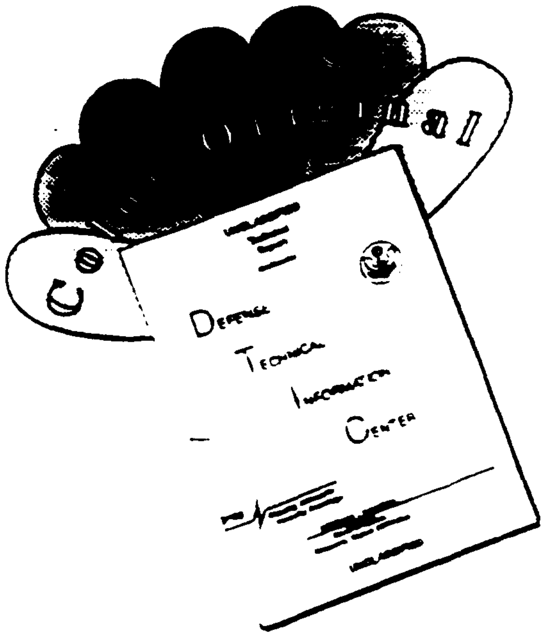

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Recent federal/military standards in the area of automatic link establishment (ALE) for HF radios have been developed that coordinate frequency selection between communicating terminals, allowing them to adapt to skywave conditions. This study focused on evaluating the utility of these state-of-the-art radios in the polar environment. A quick-look evaluation of this technology was demonstrated over a radio circuit between Christchurch, New Zealand, and McMurdo Station, Antarctica. This transauroral link, operated by the U.S. Navy for the National Science Foundation, is the primary link for all operational, logistical, and emergency communications for U.S. operations between the Antarctic and the outside world. Daily plots of the measured signal-to-noise ratio, probability of bit error, and channel quality are presented, and analyzed. Because of the initial success of this technology demonstration, additional experiments were designed for deployment in FY-1993 to answer not only operational issues, but also to collect data for further scientific studies and engineering improvements.

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HIGH FREQUENCY/AUTOMATIC LINK ESTABLISHMENT (HF/ALE) RADIO PROPAGATION TEST TO ANTARCTICA

INTRODUCTION

In the United States, the National Science Foundation (NSF) is assigned the overall responsibility for all U.S. activities in Antarctica. This arrangement, a result of a consolidation that occurred in 1971, brings together all aspects of the U.S. Antarctic Research Program (USARP), as well as all other operational activities, such as Operation Deep Freeze, that support either research or the U.S. presence in Antarctica. The NSF's Division of Polar Programs (NSF/DPP) administers the USARP. In addition to assisting in the selection of research projects, NSF/DPP is responsible for a broad range of issues, among which is the development and implementation of a comprehensive safety, environmental, and health program within Antarctica. Communication in support of this program, as well as those that ensure logistical support of the U.S. presence in the Antarctic, is the subject area of this report.

The international gateway to Antarctica is Christchurch, New Zealand. In Antarctica, McMurdo Station is the main staging area for NSF-funded scientific research. Other year-round, primary U.S. stations in the Antarctic include South Pole and Palmer. During the summer season, Byrd Station serves as a refueling stop. The U.S. Naval Support Force Antarctica (NSFA), with headquarters at McMurdo Station, and its detachment in Christchurch, New Zealand, have the primary mission to support the NSF's operations in Antarctica. The communication links between McMurdo and Christchurch serve as the primary intercontinental link between operations in Antarctica and the outside world.

During the summer season, communication support includes the maintenance of a 24-hour, two-way communications link between Christchurch and McMurdo. The daily message flow includes traffic that supports such things as logistics coordination, including airplane flight support, weather, test and maintenance, message relay for science and technical projects, as well as message relay for emergency and humanitarian purposes. During the winter, research activity is greatly reduced, with a corresponding reduction in message traffic load. Operations may be reduced to nominal daytime operations in McMurdo; however, Christchurch is required to maintain its around-the-clock operations. In general, safety, environmental, and health issues on the ice require, at least conceptually, infrequent communication services. The end users in this case are field parties that, at a minimum, are required to report their geographic position and general status daily. Though messages are usually short, the radio communications link is often disadvantaged, consisting of rudimentary antennas, limited by transmitter power and duration, and operated by personnel who are in the field for their own scientific investigations and who view communications as a service, rather than, in this context, as an art. Compound these operations with severe weather and ionospheric conditions and one can envision a rather frenetic undertaking.

Because of very similar radio communications objectives for disadvantaged users, which were an outgrowth of this Center's involvement in Arctic communications, a dialogue was initiated in early 1990 between the former Naval Underwater Systems Center (NUSC) and the NSF. By June 1991, a Memorandum of Agreement (MOA) between the two organizations was signed. It provided the vehicle through which a close interchange of ideas could take place for the benefit of their respective constituents. Under the arrangement, NUSC, would furnish technical support and conduct specific radio communications experiments. As warranted, recommendations would be provided to NSF/DPP to improve the regional, as well as intercontinental communications capability for the U.S. Antarctic program as it related to the utilization of shortwave or high frequency (HF) skywave and meteor burst scatter propagation.

Standard terrestrial communications techniques, such as MHF skywave radio, that are capable of providing both time critical, short message traffic and non-urgent, long message communications are often at jeopardy when called upon to operate a polar service. This is mainly attributable to two propagation effects associated with polar and auroral ionospheric conditions: (1) the uncertainty in short-term HF frequency selection, a frequency management issue due to the variability of the propagation modes, and (2) the occurrence of various disturbances and enhancements. Disturbances are best illustrated with such events as polar cap absorption (PCA), as well as low-level absorption events, while solar noise influxes are often enhanced. It has also been suggested that typical HF receiver noise, e.g., 5 to 10 dB/kT_0, limits reception during periods of low atmospheric noise.

HF communications are presently the primary mode by which NSFA passes information between Christchurch and McMurdo. The ability to maintain a usable HF link is an important operational and safety issue. HF communications relies on the reflecting of radiated energy off of an ever changing ionosphere with link ability that is highly frequency-dependent. Presently, operating frequencies are chosen by a trial and error basis, which, based on past experience, is inadequate during rapidly changing ionospheric conditions. Although there are computer programs that predict mid-latitude results, i.e., IONCAP (reference 1) and ASAPS (reference 2), the nature of the HF propagation path in polar regions is not well defined by existing theoretical models. The purpose of this test was to demonstrate the feasibility of using state-of-the-art HF/automatic link establishment (HF/ALE) equipment to provide user friendly, reliable HF communications over distances of thousands of miles in polar regions and to provide a database from which an improved theoretical polar propagation model could be developed.

Coordinated as a related, but separate effort, the Institute for Telecommunication Sciences (ITS), an engineering arm of the National Telecommunications and Information Administration located in Boulder, Colorado, was tasked to conduct an assessment of the HF radio communications network between Christchurch and McMurdo Station, which is maintained and operated by the NSFA. The ITS assessment was to contain specific recommendations to improve the voice and data transmission quality and to increase circuit time availability including specifications for upgrading equipment.

AUTOMATIC LINK ANALYSIS (ALE)

The U.S. government established FED-STD-1045 (reference 3) in 1990 and the more restrictive MIL-STD-188-141A (reference 4) in 1986 for the developing technology of automated adaptive frequency control for HF communications. This document defines the manner, information passed, and its format for establishing links between MIL-STD-1045 radios. The following is a brief description of the ALE procedure used for this test.

A network of two or more stations is configured by programming a common set of scan frequencies and station call names into all the network radios. Each proposed radio link is set up for periodic Link Quality Analysis (LQA) exchanges. The LQA process is explained in detail in figure 1. When a station attempts to call another network station, the calling radio automatically selects the optimum transmit frequency based on the results of the latest LQA exchange. The second station will be scanning all the network frequencies and will hear the call at the optimum frequency and will stop scanning there. A link will then be established at that frequency and normal voice or data communications can then follow.

The automatic frequency selection is accomplished through a comparison of channel ranking based on LQA calculations at all scan frequencies. The score value is calculated at each channel frequency based on (signal plus noise)-to-noise ratio (SINAD) and Pseudo Bit Error Rate (PBER) measurements at both stations. The ALE radio attempts to call the associated radio at the frequency with the highest link score based on the latest LQA. In the case where the score is identical for more than one frequency, the highest frequency is chosen. The complete LQA process for 10 scan frequencies takes approximately 3.5 minutes.

TEST LOCATIONS AND DESCRIPTION

Christchurch, New Zealand, is the staging location for transferring personnel and supplies to the main U.S. base (McMurdo Station) in Antarctica, which is located approximately 2700 miles (4347 km) due south of Christchurch. Black Island is located approximately 20 miles (32 km) south of McMurdo Station across McMurdo Sound. The coordinates of Christchurch are lat. 43°32'42"S and long. 172°37'54"E. The coordinates of Black Island are long. 166°07'47"E and lat. 78°08'31"S. The location of McMurdo Station, the Black Island remote site, and other local points of interest are shown in figure 2. An overall view of the Christchurch/McMurdo path is shown in figure 3.

Ten representative frequencies were selected between 6 and 26 MHz for evaluating the operational HF range. The frequencies and the associated channel number are listed in table 1. These frequencies are representative of those presently used for the Christchurch/McMurdo Station link by NSFA. All channels are operated in the upper sideband mode with a 3.0 kHz bandwidth, which means the energy is actually located 1.5 kHz above the center frequency.

Table 1. Scan Test Frequencies

Channel	Frequency (MHz)
01	06.767
02	07.730
03	09.215
04	11.508
05	13.490
06	14.777
07	18.610
08	20.439
09	22.950
10	25.110

The Christchurch radio equipment consisted of a Harris model RF-7210 Adaptive Frequency Controller and a RF-350K 100 watt HF transceiver. The controller provided a "data logger" output which dumped LQA measurements and calculations in real time to a computer. The radio used at Black Island was a Harris RF-5020 HF transceiver with the ALE option installed. An overall block diagram of the radio gear is shown in figure 4.

An existing rhombic antenna at Black Island and a temporarily installed sloping vee antenna at Christchurch were the antennas used for the test. Each antenna was a broadband-type that operated over the entire test frequency range without the need of a tuning network. The specific dimensions and parts used for the rhombic and sloping vee antennas are shown in figures 5 and 6, respectively. The voltage standing wave ratio (VSWR) of the sloping vee was measured with a network analyzer with the transmission line effects calibrated using standard loads placed at the end of the line. A VSWR meter was not available at Black Island so the return loss was measured with a spectrum analyzer and VSWR was calculated from that value. The VSWR values are listed for both antennas in table 2. It should be noted that the frequencies at which the VSWR measurements were taken do not exactly match up with the scan frequencies.

The theoretical gain and pattern of the sloping vee have been modeled using the computer program Numerical Electromagnetics Code (NEC), version NEC-2 (reference 5). This analysis and the gain and pattern are contained in appendix B.

DATA ANALYSIS

During the 11 day period of this test 19,577 individual channel scores were calculated from SINAD's and PBER's measured at both Christchurch and Black Island. The channels evaluated per day ranged from a minimum of 670 to a maximum of 2873. LQA's were repeated on 5 minute, 30 minute and 1 hour intervals, depending on other tests which required the dedicated use of the transceivers. A complete listing of the data is included in a separate technical memorandum (reference 6).

The LQA data values obtained from measurements must be related to the measurement time and frequency if usable propagation information is to be extracted. Three-dimensional data (time/frequency/data value) has been plotted in an X-Y Cartesian graph where the X axis represents the time, the Y axis represents the frequency and color rectangles represent the data values. Colors, corresponding to a predetermined magnitude ranges, provide the third dimension information. The color ranges are based on ranges of SINAD values which are referenced to the value of 12 dB which is the generally accepted threshold for intelligible voice communications. Digital communication is possible over radio links with SINAD's lower than 12 dB. In an attempt to present the measurements in a logical format related to the ability to communicate, measurements are grouped into magnitude ranges associated with a color corresponding to levels of communication ability as diagrammed in table 1.

Table 2. VSWR of the Sloping Vee and Rhombic Antennas

Frequency (MHz)	Sloping Vee VSWR	Rhombic VSWR
6.767	2.85	1.4
7.730	2.2	1.2
9.1205	1.5	1.4
11.508	1.3	1.2
13.490	1.7	1.0
18.610	1.3	1.2
20.439	1.5	1.2
22.950	1.3	1.2
25.110		1.1

Table 3. Channel Measurement Levels vs. Communication Ability

SINAD Value (dB)	Score Value	Color	Communication Ability
15-21	75-90	Red	Twice (+3 dB) or more than enough signal power for voice comms
12-14	65-74	Yellow	Intelligible voice comms
6-11	40-64	Green	Successful digital comms
1-5	1-39	Blue	Marginal digital comms

Each plot in this report contains data for a single Greenwich Mean Time (GMT) day. HF propagation characteristics vary in a cyclic daily manner because they are highly dependent on the relative position of the sun to the communication sites. By displaying the data in this manner, the daily propagation cycles can be characterized, which provides the radio operator with a guideline for frequency selection. Figures 7 and 8 are LQA Score and SINAD plots, respectively, of the data for the 15 January 1992. The measured SINAD and PBER at Christchurch and Black Island and the calculated channel score and SINAD difference are plotted in appendix B for all 11 days of testing starting on 13 January and ending on 23 January 1992.

LQA scores of greater than 65 indicate that a channel can support intelligible voice communications. As can be observed in figure 7, and what is consistent for all measured days, the tested Harris HF/ALE system was able to establish voice quality links at virtually all times of the day. For purposes of describing the data within the plots, the highest frequency at which a link was established during an LQA operation will be referred to as the Maximum Measured Frequency (MMF) and the lowest link frequency is referred to as the Lowest Measured Frequency (LMF). The MMF and LMF are functions of distance between stations, ionospheric conditions, noise levels, antenna gain, and transmit power. The frequency at which the highest score was calculated for a given test period will be referred to as the Optimum Measured Frequency (OMF). The MMF, LMF, and OMF values for a given day can be connected together to form three curves. Because of the variable nature of the data, it was decided to construct the curves based on visual interpolation of the data. The interpolated data is listed in tables 4, 5, and 6. To demonstrate the daily periodicity and consistency of the data, the MMF, LMF, and OMF curves for the 11 test days are plotted in figures 9, 10, and 11, respectively. The average MMF, LMF, and OMF curves based on the data from tables 4, 5, and 6 are plotted in figure 12. Typically, the MMF made a sharp dip in value between 0900 and 1500 hours, bottomed out between 1300 and 1500 hours and increased rapidly between 1500 and 1900 hours. The OMF generally followed the MMF variation. The LMF varied much less than the MMF and OMF and it had a broad minimum around 1200 hours. The OMF ranged from a high of near 22 MHz to a low near 11 MHz. During a majority of an average test day, the OMF changed at a rate of about 1 MHz per hour. The most obvious variations that are observable between plots of different days are in the depth and sharpness of the MMF dip and the peak value of the MMF at times away from the dip.

The difference between the SINAD's measured at Christchurch and McMurdo were plotted for each day to observe the reciprocity of the radio path. The largest differences in measured signals were present at the MMF and near local midnight time. Most of the time, when links were made at the highest available frequency (25.11 MHz), there were large differences in measured SINAD. During the 12-day test period, solar activity was generally quiet. Solar activity was greatest at the beginning of the test period and generally became quieter as each day passed.

Table 4. Maximum Measured Frequency Data for Seven Test Days

GMT Hour	22 Jan	20 Jan	19 Jan	18 Jan	17 Jan	16 Jan	15 Jan	AVG MMF
0	25.27	22.60	22.75	25.19	22.75	22.75	19.93	23.03
100	25.27	22.75	24.89	25.19	22.83	22.75	20.08	23.39
200	25.27	23.36	22.83	25.19	22.91	22.75	20.08	23.20
300	25.19	25.50	24.43	25.19	22.83	22.75	20.16	23.72
400	25.19	23.67	25.50	25.19	22.68	22.75	20.16	23.59
500	24.81	23.21	25.50	25.12	22.75	22.75	19.47	23.37
600	24.04	22.98	25.50	25.19	22.68	22.75	16.72	22.84
700	23.43	21.15	24.20	24.36	22.14	22.3	15.66.	21.89
800	22.74	20.54	23.44	23.67	21.07	19.93	15.28	20.95
900	21.90	20.16	22.83	22.30	20.08	18.71	15.05	20.15
1000	20.37	19.78	22.60	17.41	19.47	17.56	14.74	18.85
1100	17.53	16.11	20.31	15.12	16.19	16.19	14.66	16.59
1200	14.77	14.82	14.74	14.74	15.20	15.20	13.14	14.66
1300	13.78	14.59	17.95	14.66	14.74	14.28	11.08	14.44
1400	9.33	14.44	20.08	14.59	14.74	13.67	9.09	13.71
1500	9.26	13.67	15.66	14.66	14.82	14.51	10.32	13.27
1600	12.48	13.29	14.66	14.97	15.20	14.66	17.95	14.74
1700	15.39	13.14	14.66	15.20	15.81	15.50	18.71	15.49
1800	19.91	15.20	17.72	16.50	17.79	16.95	19.47	17.65
1900	25.04	20.01	22.91	22.37	23.29	18.56	19.93	21.73
2000	25.27	20.16	23.90	24.89	25.19	20.69	20.62	22.96
2100	23.35	20.08	25.50	25.50	25.50	22.14	21.15	23.32
2200	22.90	20.23	25.58	25.58	25.58	22.83	22.14	23.55
2300	23.58	18.63	25.50	25.58	25.58	22.98	22.60	23.49
2400	25.35	22.60	25.58	25.50	25.58	22.98	22.91	24.36

Table 5. Optimum Measured Frequency Data for Seven Test Days

GMT Hour	22 Jan	20 Jan	19 Jan	18 Jan	17 Jan	16 Jan	15 Jan	AVG OMF
0	23.00	22.10	22.30	22.91	22.52	22.68	18.02	21.94
100	22.13	21.10	21.23	22.60	22.14	21.61	17.87	21.24
200	21.52	20.50	20.92	22.37	21.53	20.31	16.95	20.59
300	21.13	19.60	21.61	22.14	20.77	18.71	16.42	20.05
400	20.90	18.40	21.23	21.23	20.23	18.02	16.04	19.44
500	19.52	17.80	20.31	20.54	19.78	17.79	15.58	18.76
600	18.15	17.00	19.70	17.00	18.71	17.56	15.05	17.59
700	17.07	16.20	19.09	18.02	18.25	16.72	14.21	17.08
800	15.92	15.60	18.25	17.26	17.34	16.04	13.29	16.24
900	14.01	14.30	16.95	16.04	16.11	15.28	12.76	15.06
1000	12.94	12.70	16.27	14.89	15.58	14.28	11.99	14.09
1100	13.24	11.00	15.2	13.14	15.05	12.91	9.93	12.92
1200	12.55	10.40	13.83	12.22	14.13	11.69	8.79	11.94
1300	10.18	9.93	12.45	12.15	12.99	11.23	8.41	11.05
1400	8.65	9.86	11.31	12.76	12.38	11.08	8.79	10.69
1500	8.57	10.10	13.14	12.83	11.46	11.84	9.40	11.05
1600	9.33	10.20	11.46	11.46	11.00	12.38	10.16	10.86
1700	11.02	10.70	11.46	12.60	12.07	13.52	12.15	11.93
1800	12.63	11.70	13.14	12.99	12.91	14.51	13.52	13.06
1900	14.24	13.10	13.37	13.37	14.21	15.35	14.82	14.07
2000	16.23	13.90	15.28	14.59	16.27	15.96	15.81	15.43
2100	17.92	15.10	17.18	17.41	19.17	16.42	17.18	17.19
2200	19.37	16.30	19.4	19.62	20.46	17.03	16.80	18.42
2300	20.67	18.00	21.23	21.30	21.68	17.56	17.72	19.73
2400	22.13	19.20	23.06	22.30	22.60	18.10	18.25	20.81

Table 6. Lowest Measured Frequency Data for Seven Test Days

GMT Hour	22 Jan	20 Jan	19 Jan	18 Jan	17 Jan	16 Jan	15 Jan	AVG LMF
0	11.02	8.56	11.00	11.08	11.61	8.56	11.00	10.40
100	10.94	8.26	11.00	10.77	11.15	8.26	11.00	10.20
200	10.94	8.03	11.00	10.47	10.93	7.80	11.00	10.02
300	10.25	7.95	10.50	10.24	10.39	7.42	11.00	9.68
400	9.49	7.95	8.48	9.86	10.10	7.26	9.48	8.95
500	8.49	7.80	7.64	8.87	9.93	7.19	8.10	8.29
600	7.96	7.64	7.34	7.64	8.87	7.19	7.49	7.73
700	7.73	7.49	7.19	7.34	7.72	6.96	7.34	7.40
800	7.34	7.26	6.88	7.03	7.26	6.81	6.96	7.08
900	6.88	6.88	6.58	6.81	6.88	6.65	6.96	6.81
1000	6.65	6.73	6.58	6.58	7.03	6.50	6.96	6.72
1100	6.58	6.58	6.50	6.42	6.81	6.50	6.50	6.56
1200	6.42	6.42	6.42	6.50	6.58	6.50	6.50	6.48
1300	6.5	6.42	6.88	6.88	6.42	6.50	6.50	6.59
1400	6.81	6.50	7.11	6.73	6.65	6.81	6.50	6.73
1500	7.04	6.50	7.26	7.26	6.88	7.03	6.88	6.98
1600	7.27	6.73	7.26	7.34	7.19	7.34	7.26	7.20
1700	7.65	6.96	7.26	7.34	7.72	7.72	7.64	7.47
1800	7.73	7.57	7.34	7.49	8.48	7.95	7.95	7.79
1900	7.73	7.72	7.49	7.34	9.63	7.95	7.72	7.94
2000	7.8	8.10	7.64	7.42	10.24	8.18	7.57	8.14
2100	8.03	8.26	8.03	7.57	10.85	8.94	8.18	8.55
2200	8.65	8.33	8.10	7.80	11.08	9.93	10.01	9.13
2300	9.95	8.41	8.26	7.95	11.08	10.93	10.54	9.59
2400	11.48	8.64	8.48	8.71	11.23	11.61	11.31	10.21

CONCLUSIONS

At virtually all times when measurements were taken, there existed at least one frequency where good voice communications, defined by a SINAD of 12 dB or greater, were possible. The MIL-STD-188-141A compliant equipment that was tested demonstrated the ability to automatically manage frequency selection during the test period.

During the time period of this test, solar activity was generally quiet and attempts to correlate solar geophysical data such as sun spot number, 10.7 cm radio flux and K-indices to anomalies in MMF/OMF/LMF curves proved inconclusive. It would be expected that if significant solar storms were present during periods of LQA measurements, that the measured MMF/LMF envelope and optimum communication frequencies would be significantly altered from the average during quiet times. The long term testing scheduled during 1992/1993 is expected to provide confirmation of this assumption.

FUTURE PLANS

LQA data will be collected over a 15 month period beginning in November 1992 for three southern polar links, each with site separation greater than 2500 km. One link will be intracontinental between McMurdo Station and Davis Station. Two links will be intercontinental with one between McMurdo and Christchurch, New Zealand, and the other between Davis and Salisbury, Australia. The Christchurch and McMurdo sites will be maintained by U.S. Navy personnel while members of the Australian Defense Science and Technology Organization (DSTO) will maintain the Davis and Salisbury sites. Software is presently being developed by Naval Undersea Warfare Center (NUWC) personnel to control data acquisition and to automate an exchange schedule between the four radio sites. Analysis of data will be a joint effort between DSTO and NUWC.

All LQA data recorded during the test period starting on 13 January 1992 and ending on 23 January 1992 is available on a disk from the authors. Data is presented on 11 Microsoft Excel data files (reference 4) with each file containing all data from a single GMT day.

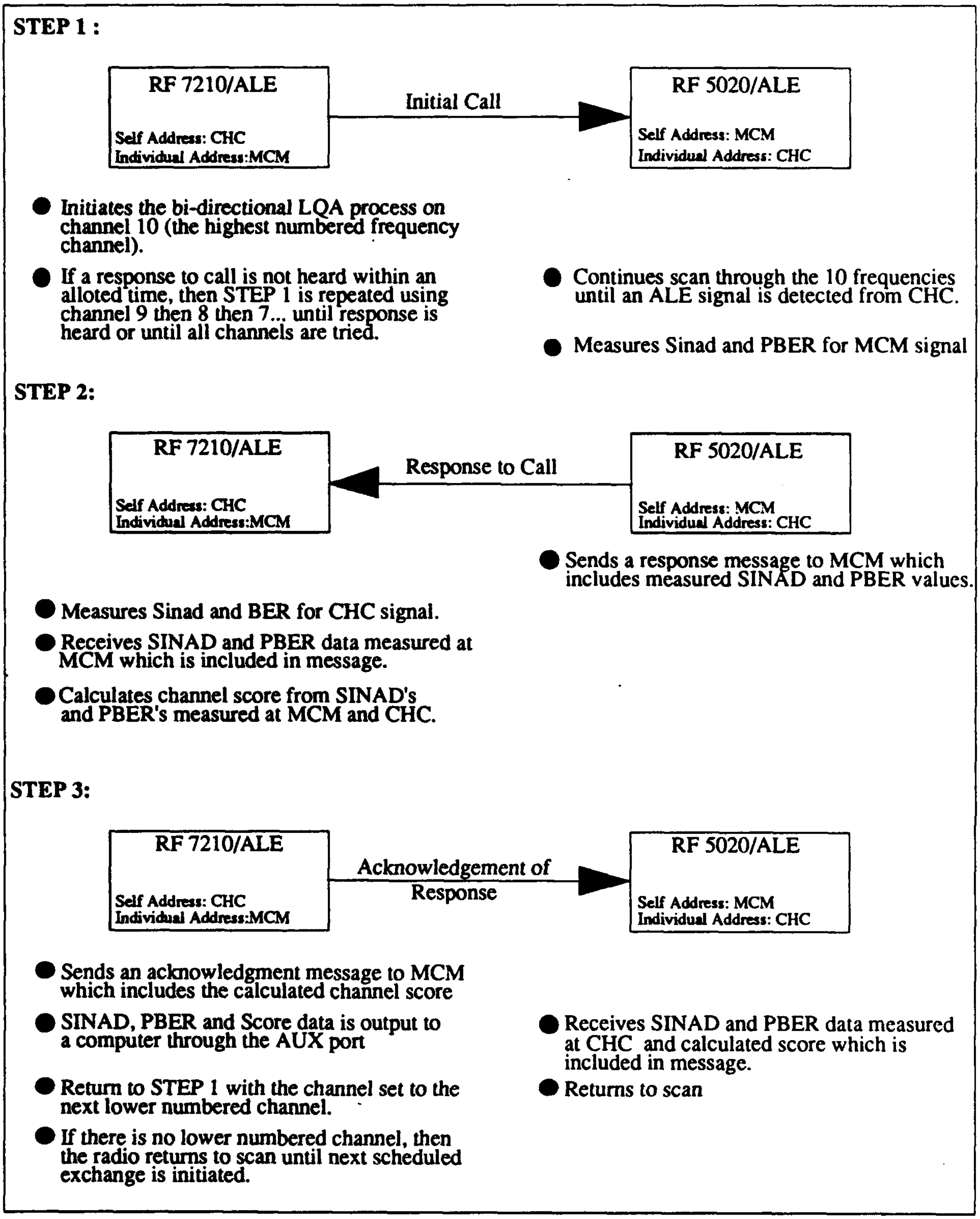

Figure 1. Description of the Three-Way LQA Exchange Process

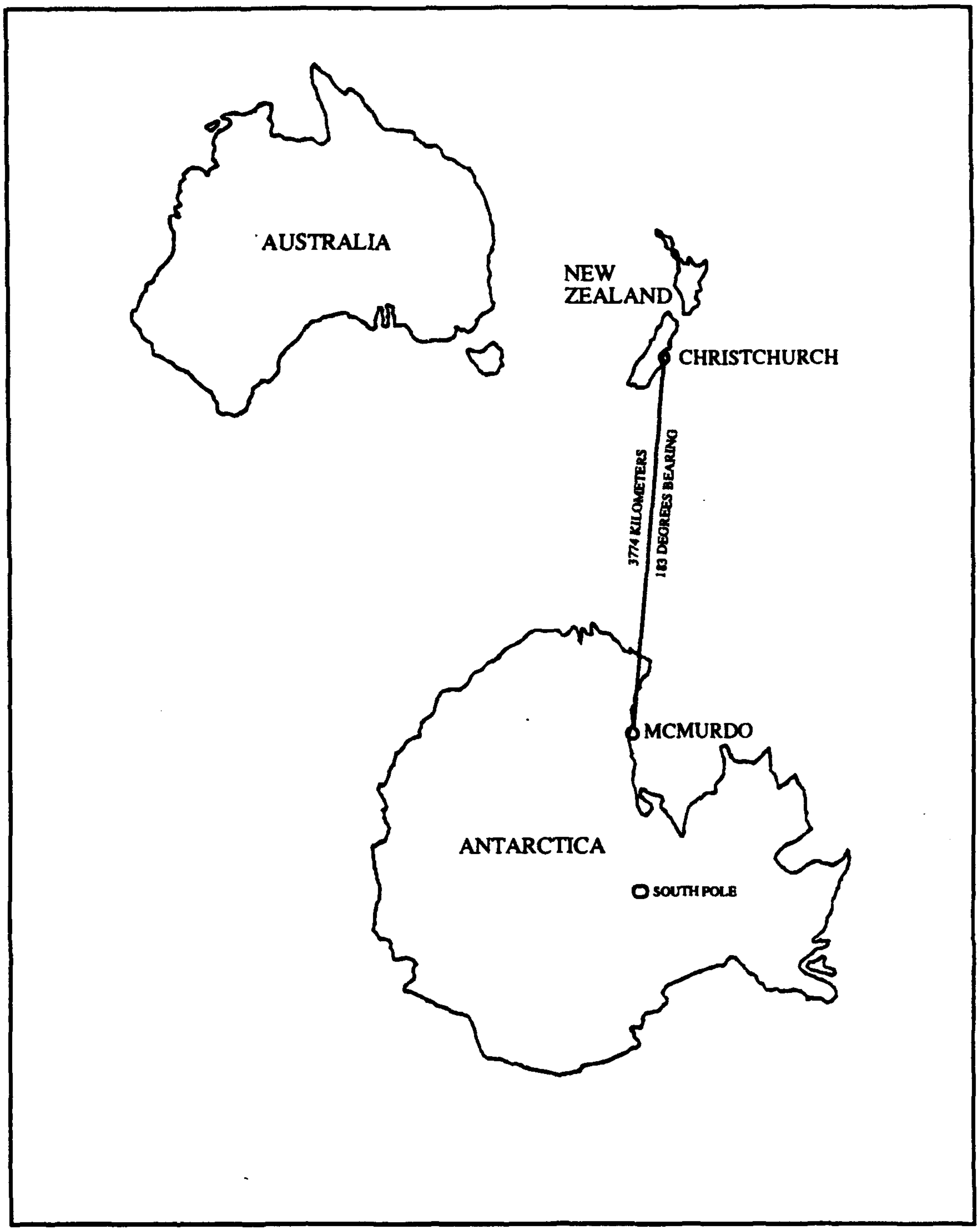

Figure 2. Map of Christchurch to McMurdo HF Propagation Path

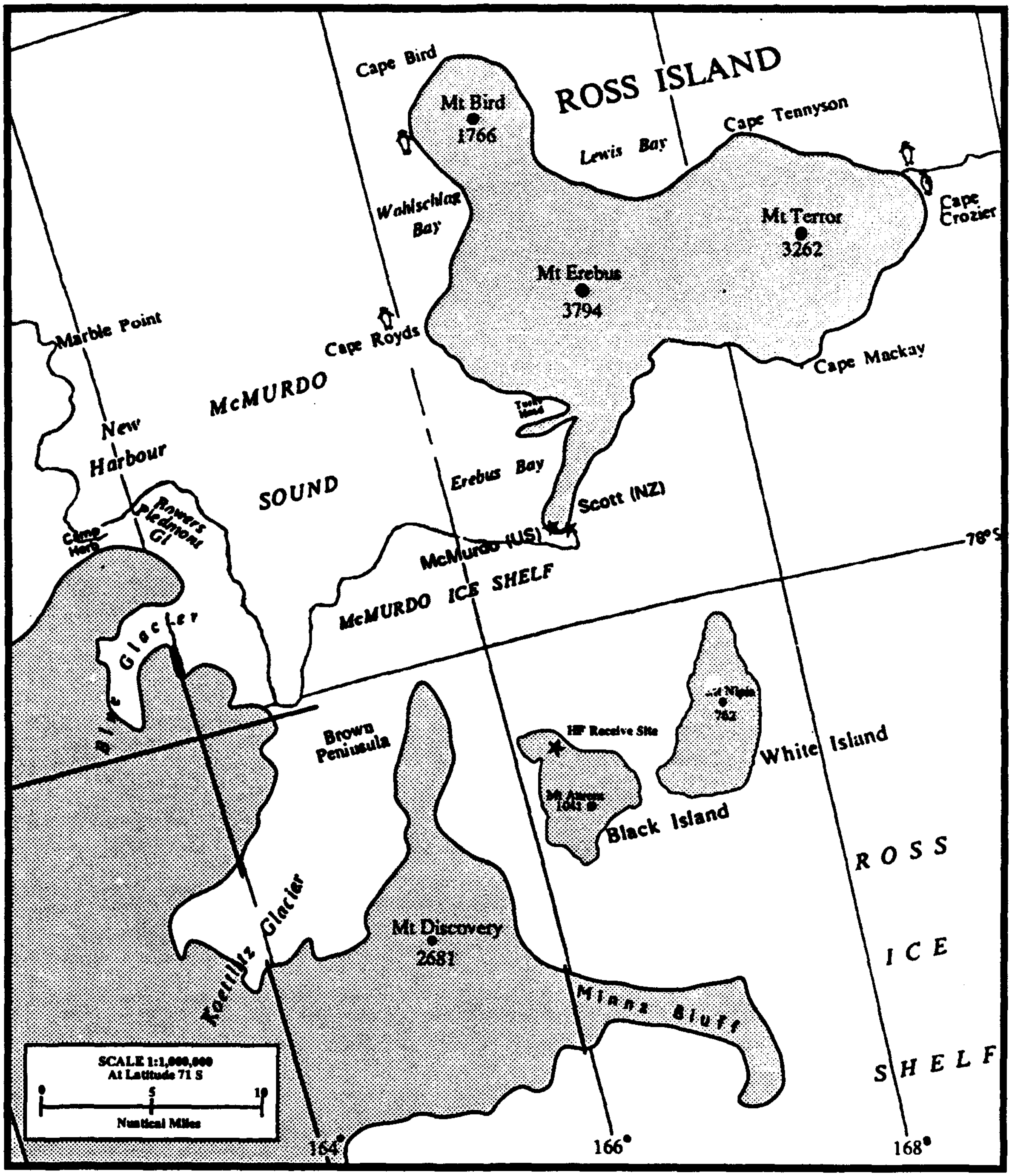

Figure 3. Ross Island and Black Island Region Map

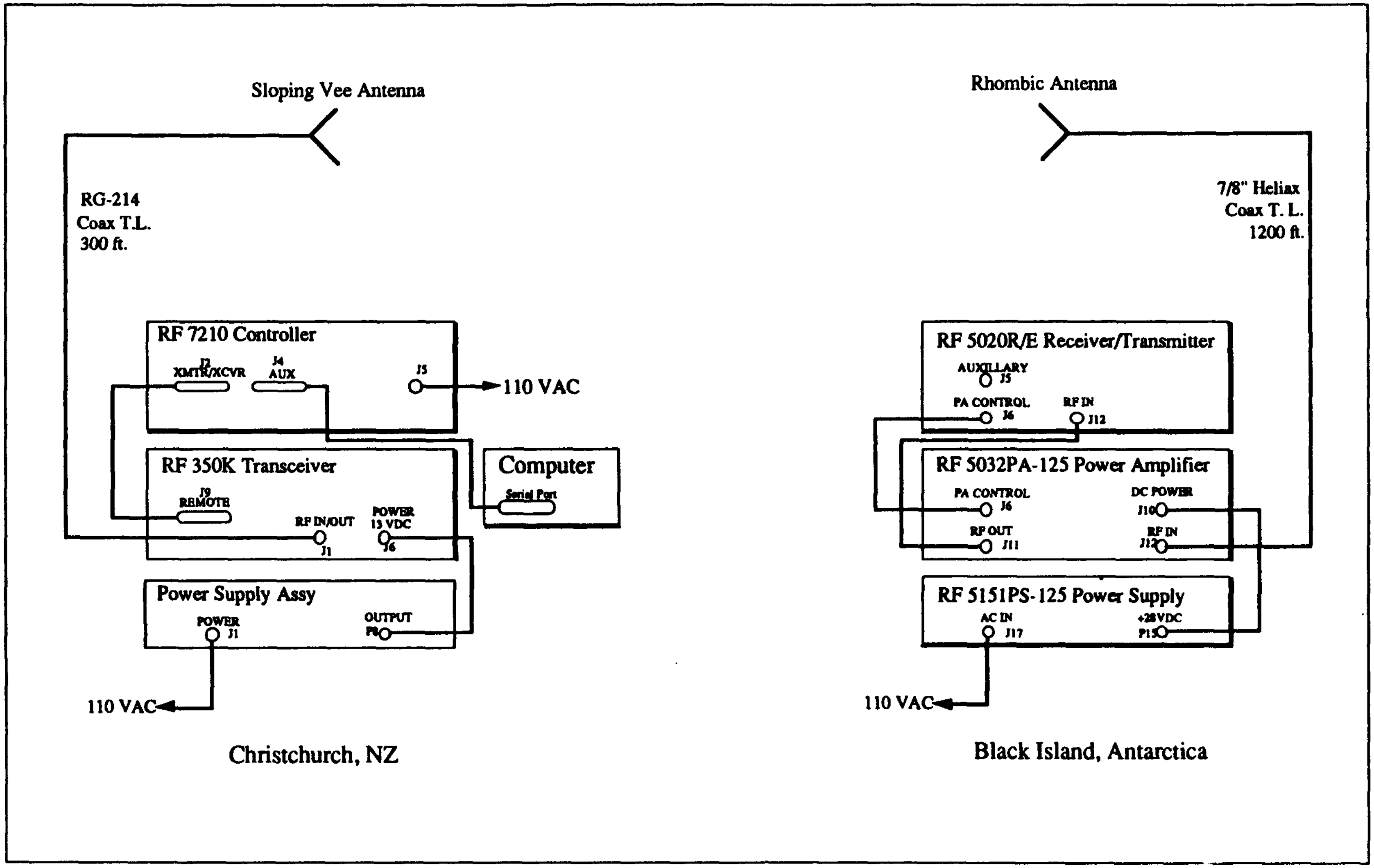

Figure 4. Block Diagram Of Equipment Set-Up

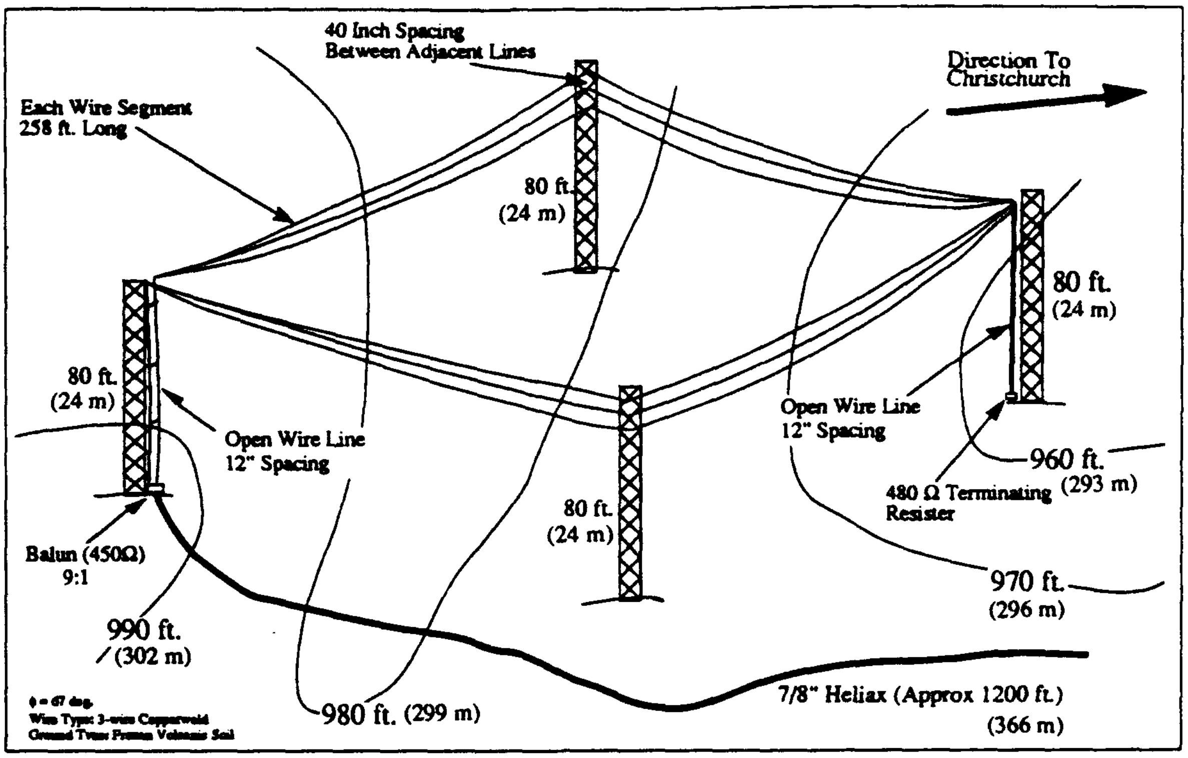

Figure 5. Black Island Rhombic Antenna - Dimensions and Ground Contour Lines

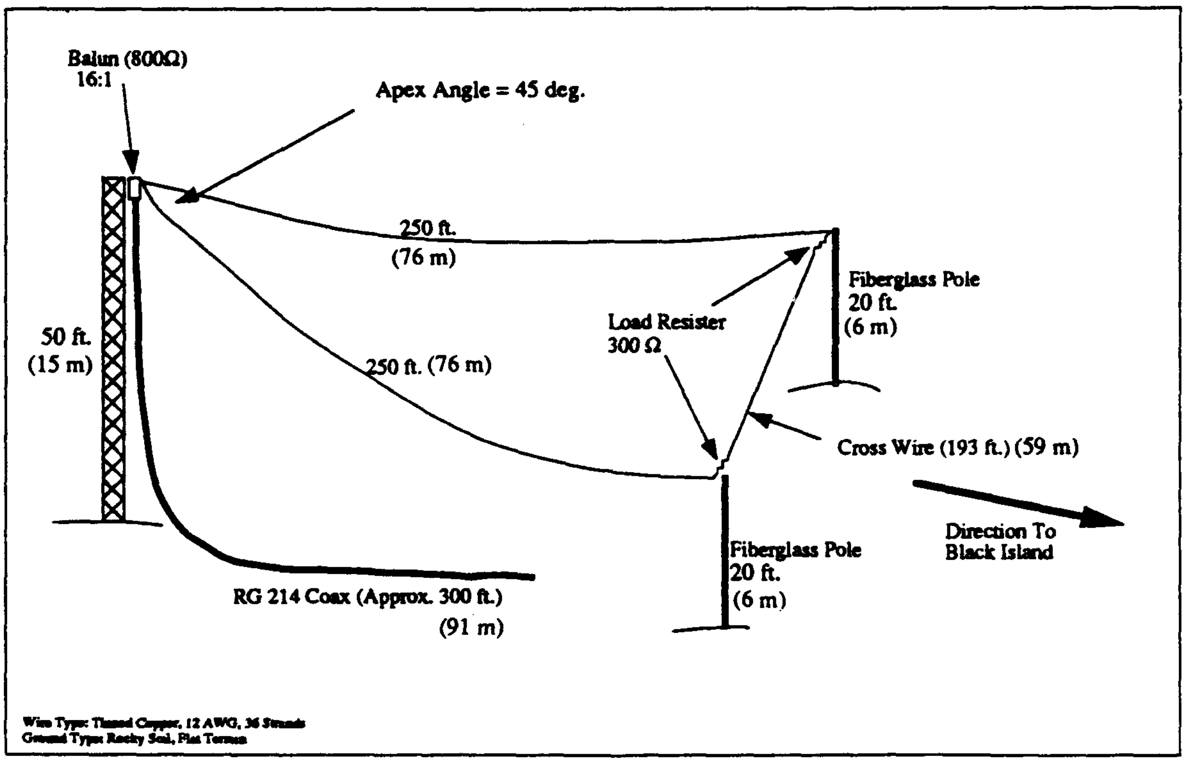

Figure 6. Christchurch Sloping Vee Antenna - Dimensions

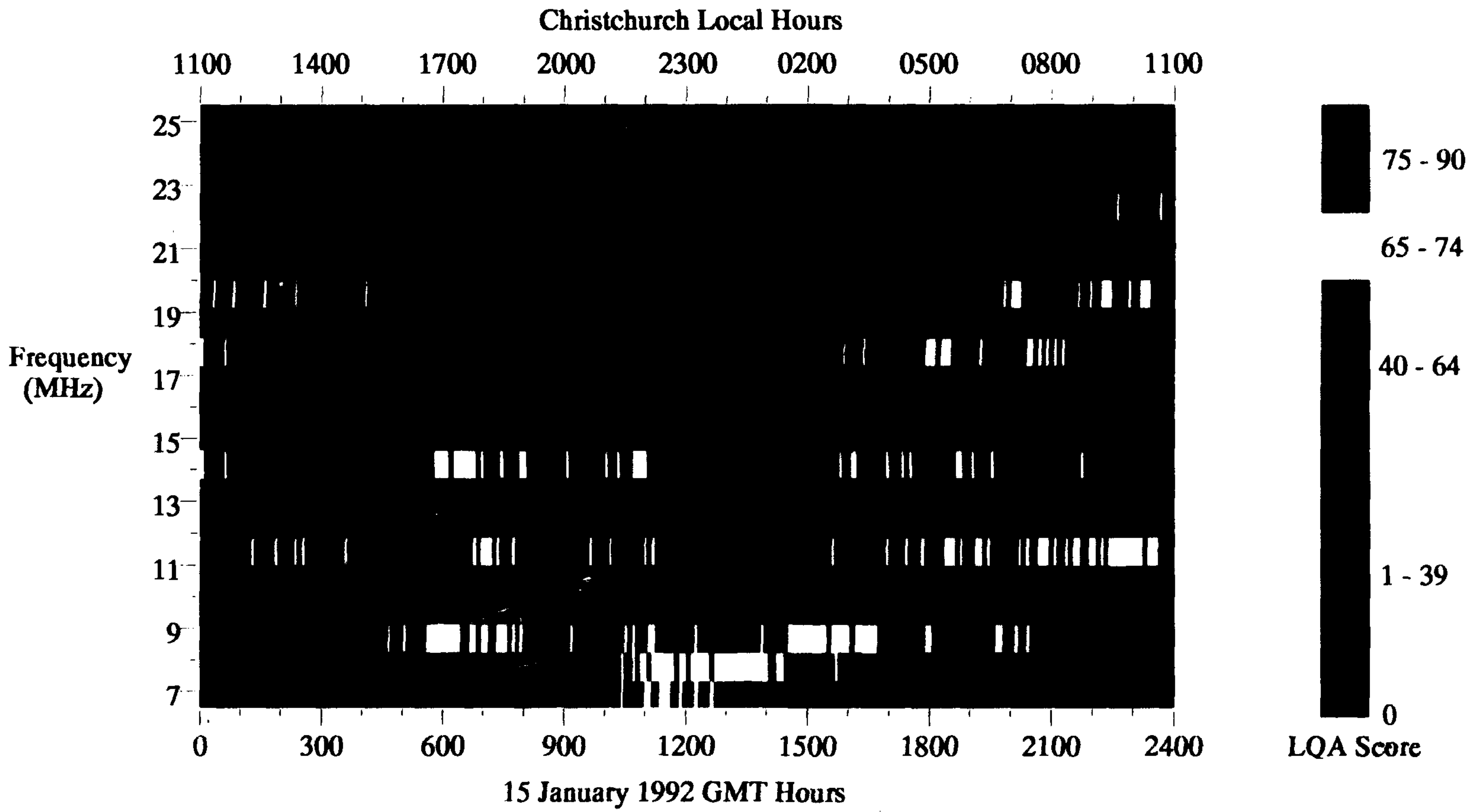

Figure 7. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 15 January 1992

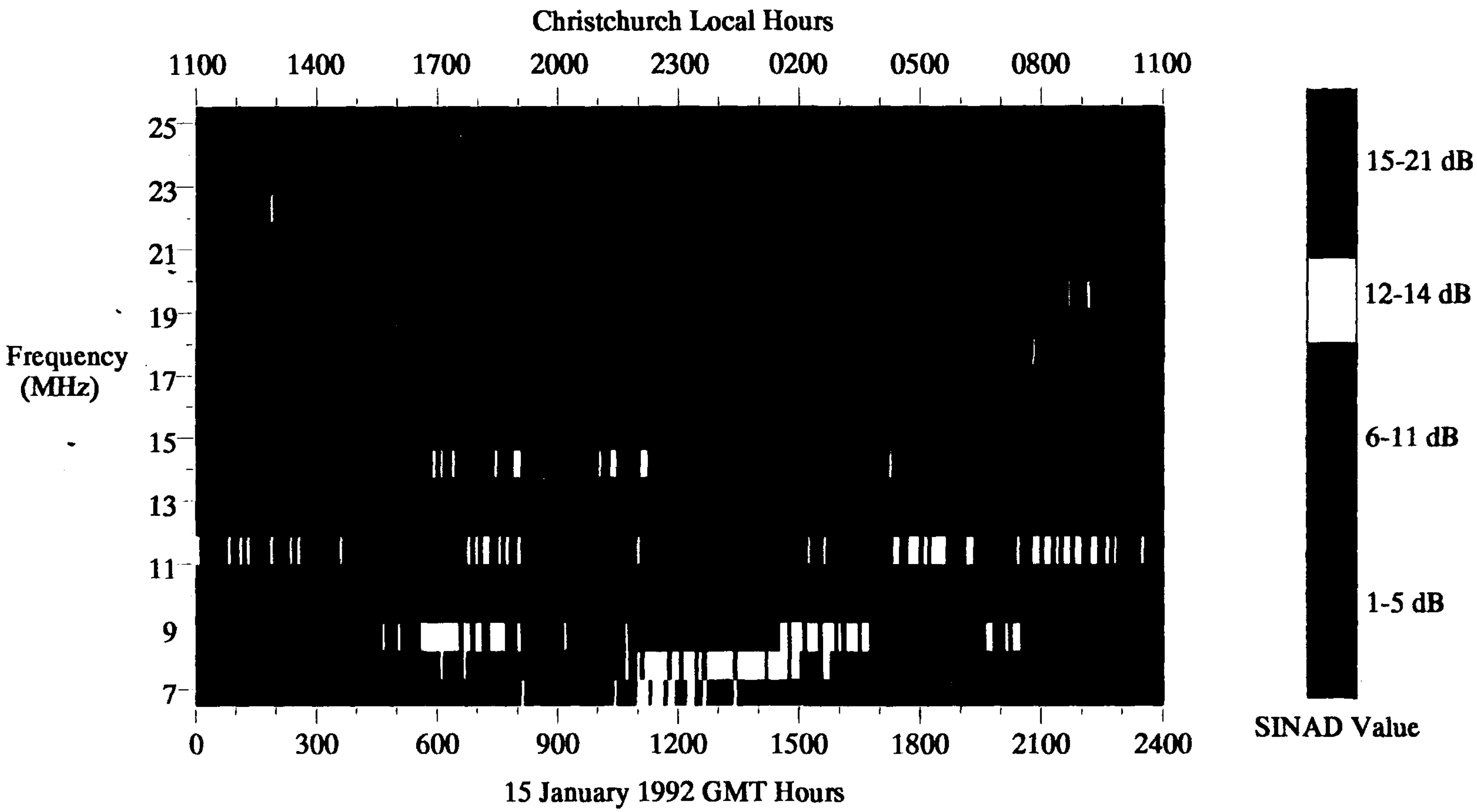

Figure 8. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 15 January 1992

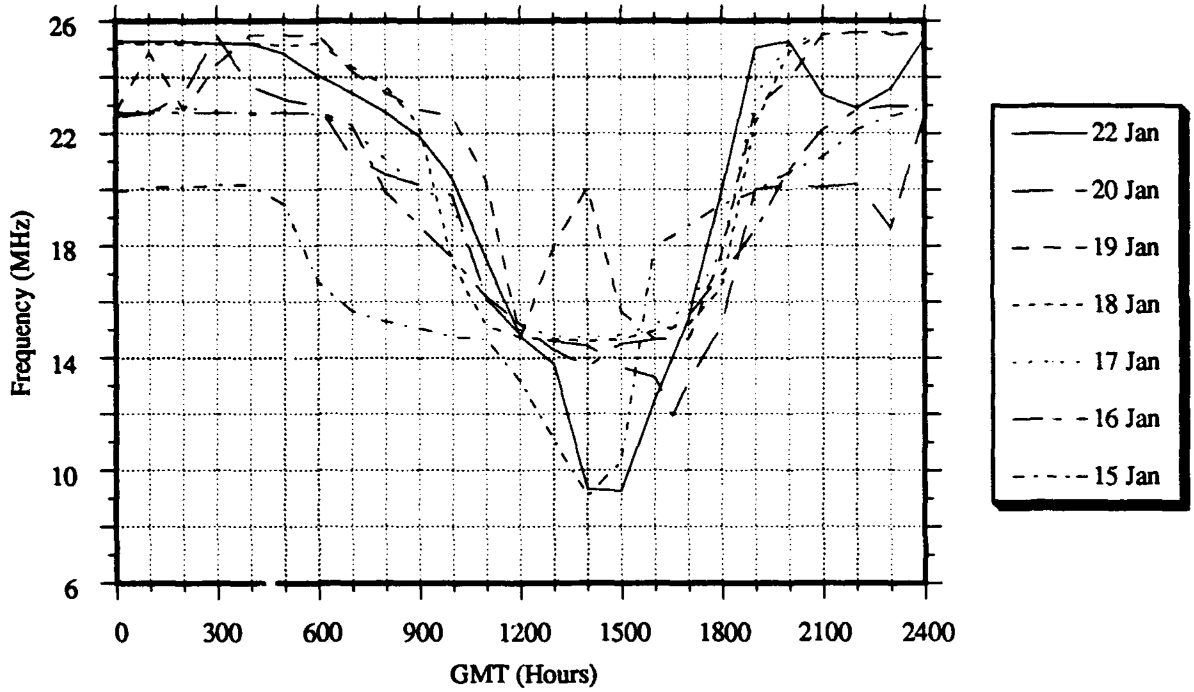

Figure 9. Maximum Measured Frequency (MMF) Curves for Seven Test Days

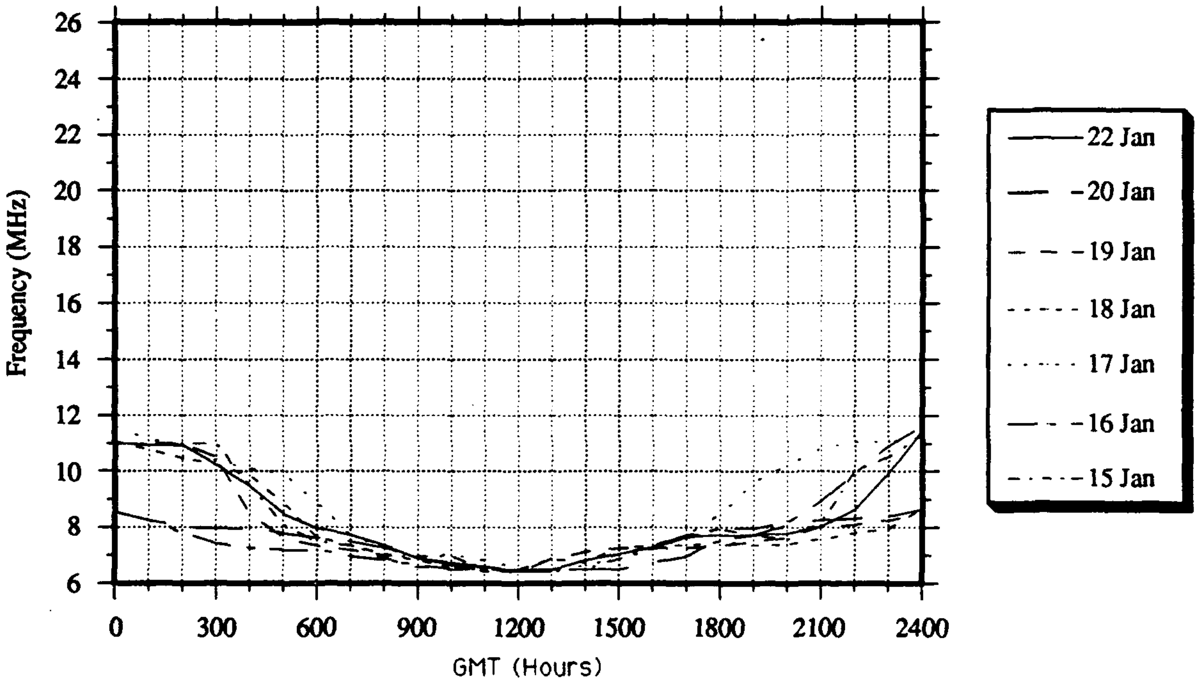

Figure 10. Lowest Measured Frequency (LMF) Curves for Seven Test Days

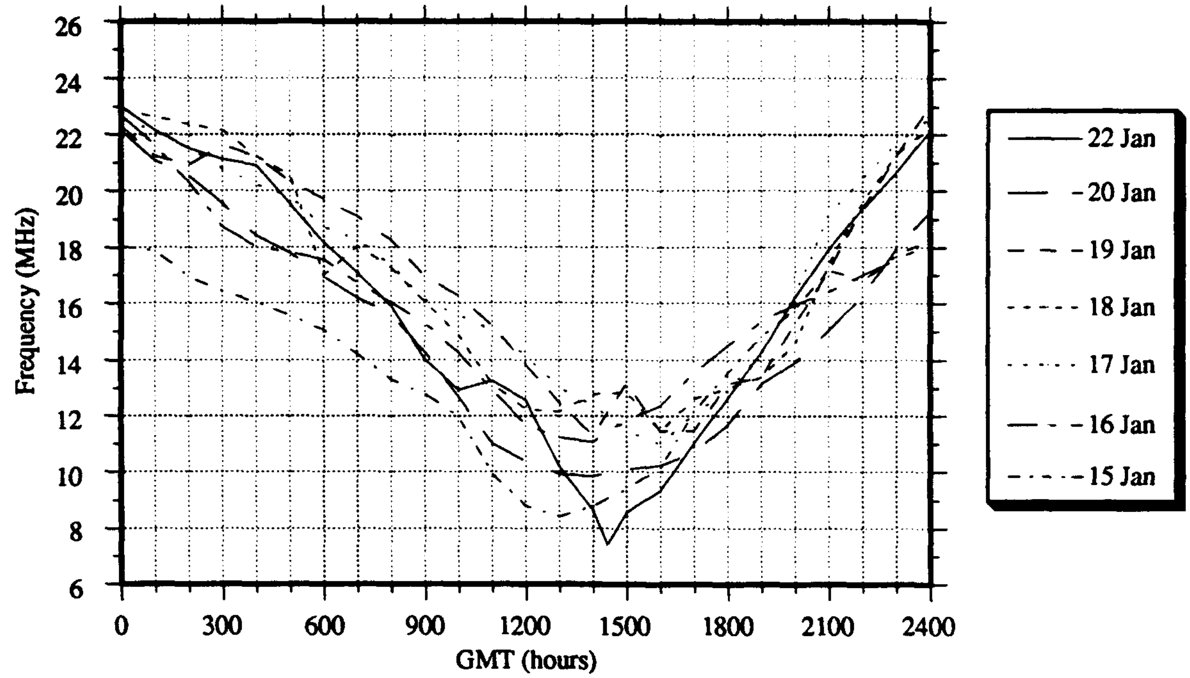

Figure 11. Optimum Measured Frequency (OMF) Curves for Seven Test Days

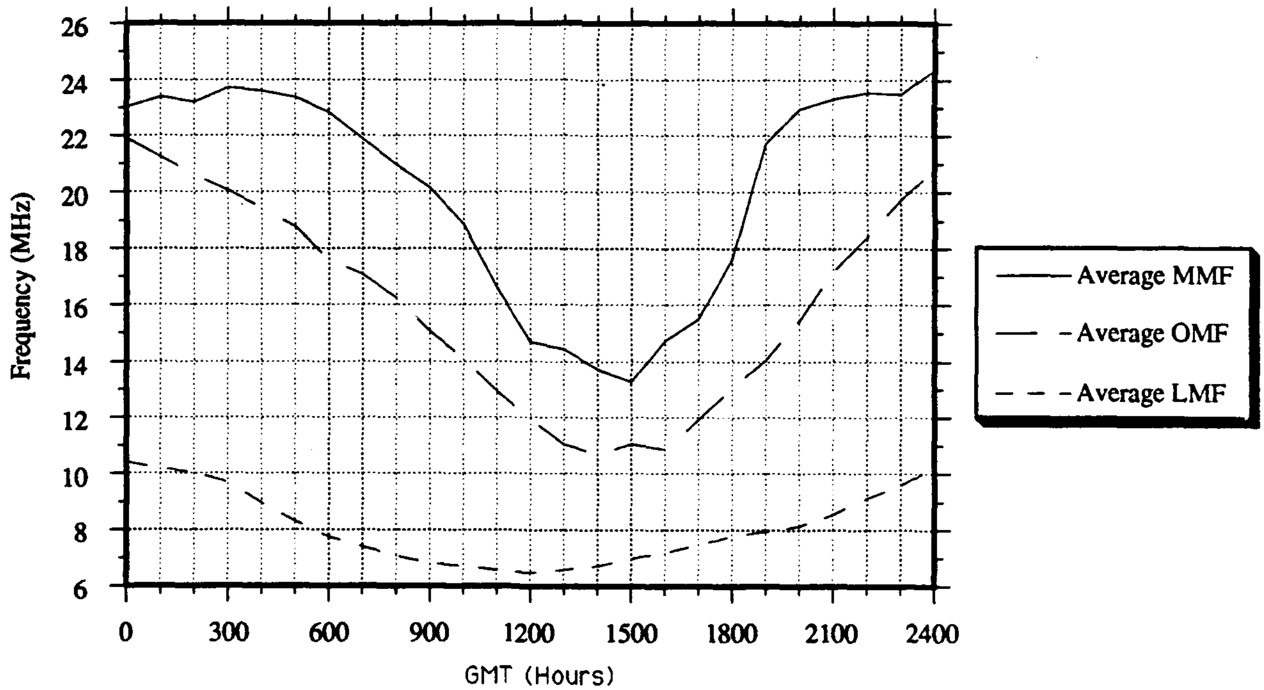

Figure 12. Average MMF, LMF And OMF Curves for Seven Test Days

APPENDIX A

PLOTS OF LQA DATA

This appendix contains plots (figures A-1 through A-66) of the LQA quantities Score, SINAD and PBER measured at both Christchurch and Black Island, and the SINAD difference between the measured Christchurch and Black Island values.

Repeating interval measurements started at approximately 0930 hours GMT on 13 January 1992. No measurements were recorded on 14 January between approximately 1130 and 2345 hours GMT. One to two hour interruptions in the measurement process occurred on most test days. Some of the reasons for interruptions were conflicts with other tests, operator error and lost data due to insufficient room on the recording media. The 9.215 MHz frequency was not programmed properly on the RF 5020 located at Black Island during the approximate time period 0000 hours, 17 January, through 0500 hours, 19 January. Thus, a measurement was not possible at that frequency during that time.

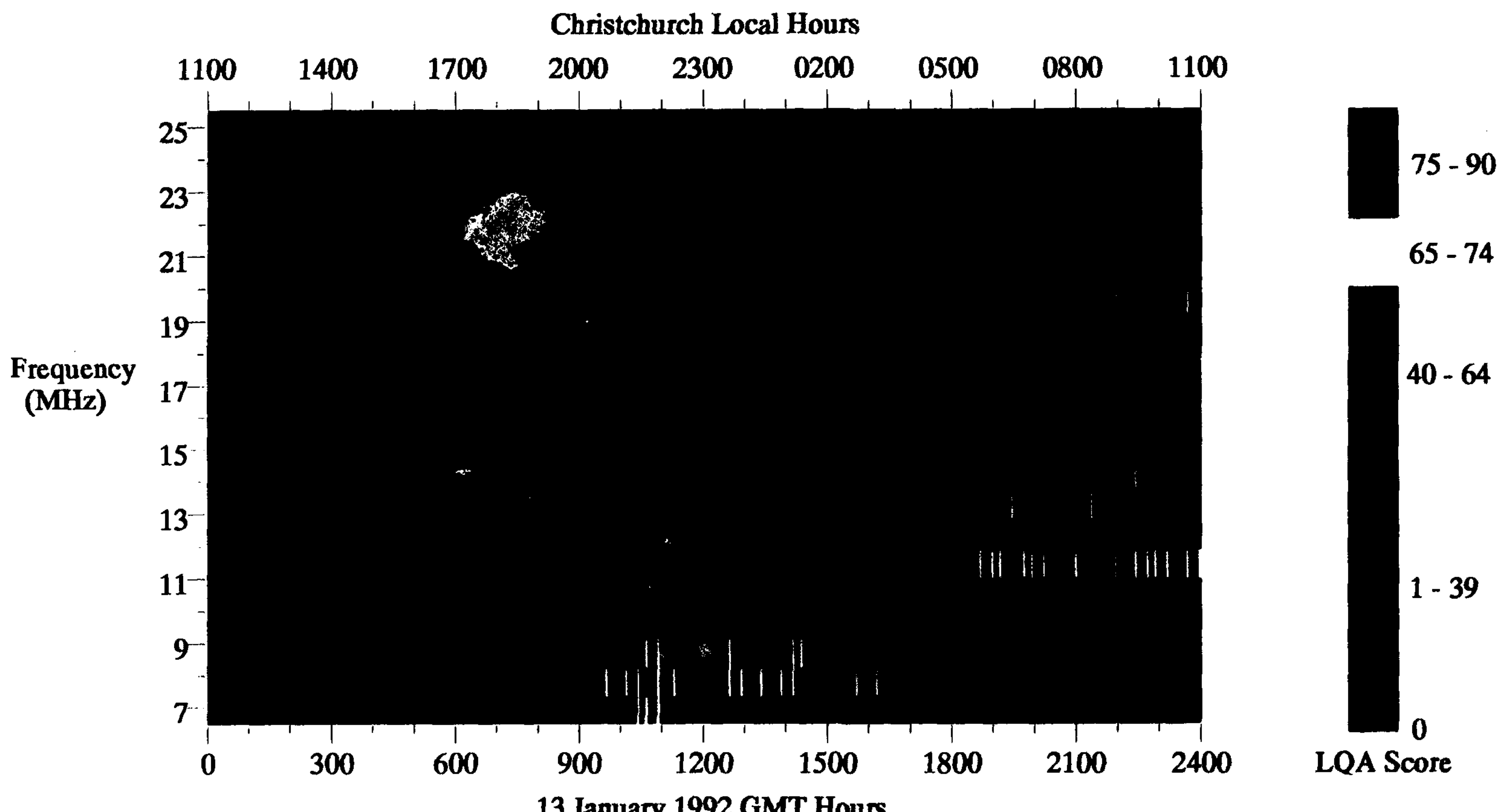

Figure A-1. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 13 January 1992

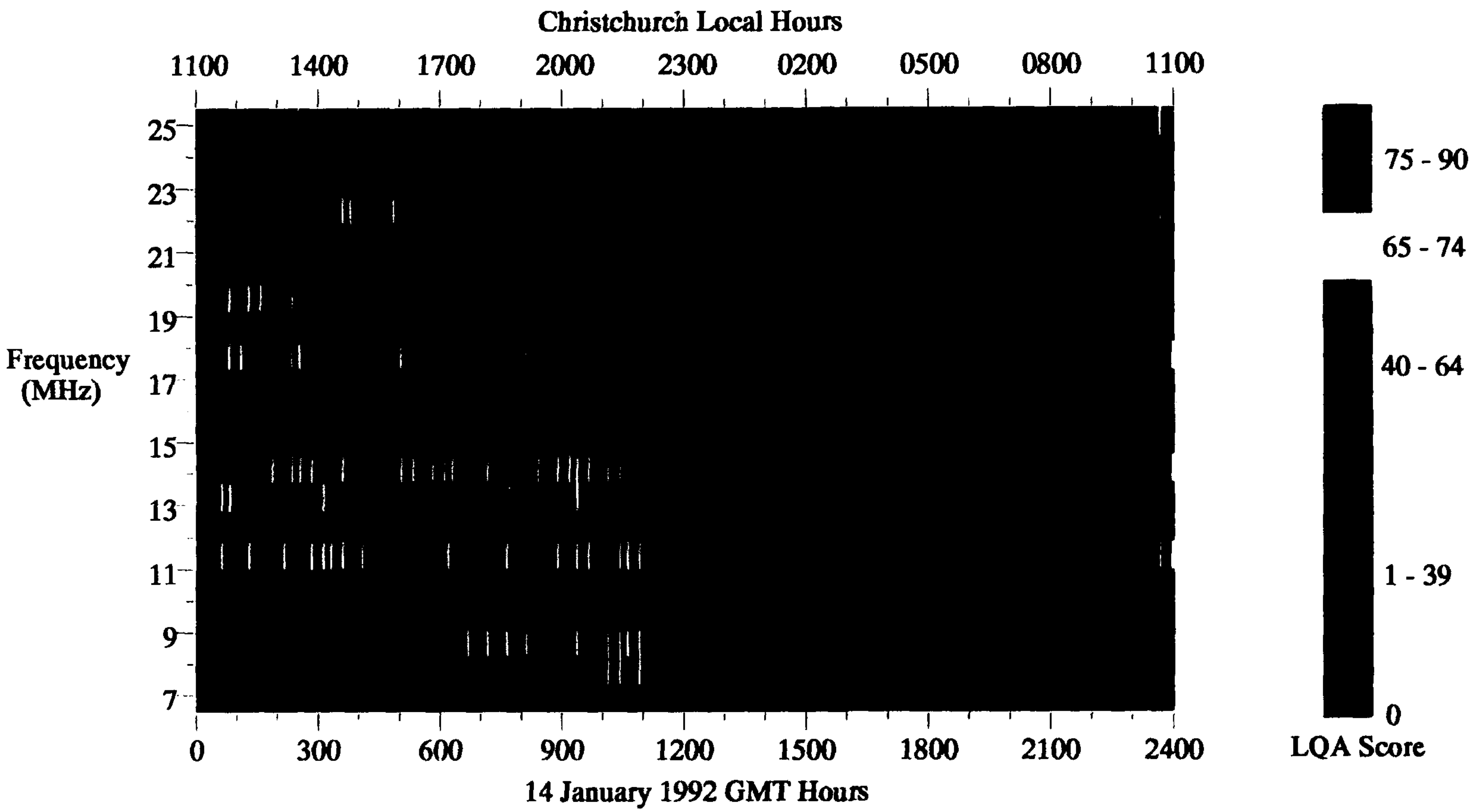

Figure A-2. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 14 January 1992

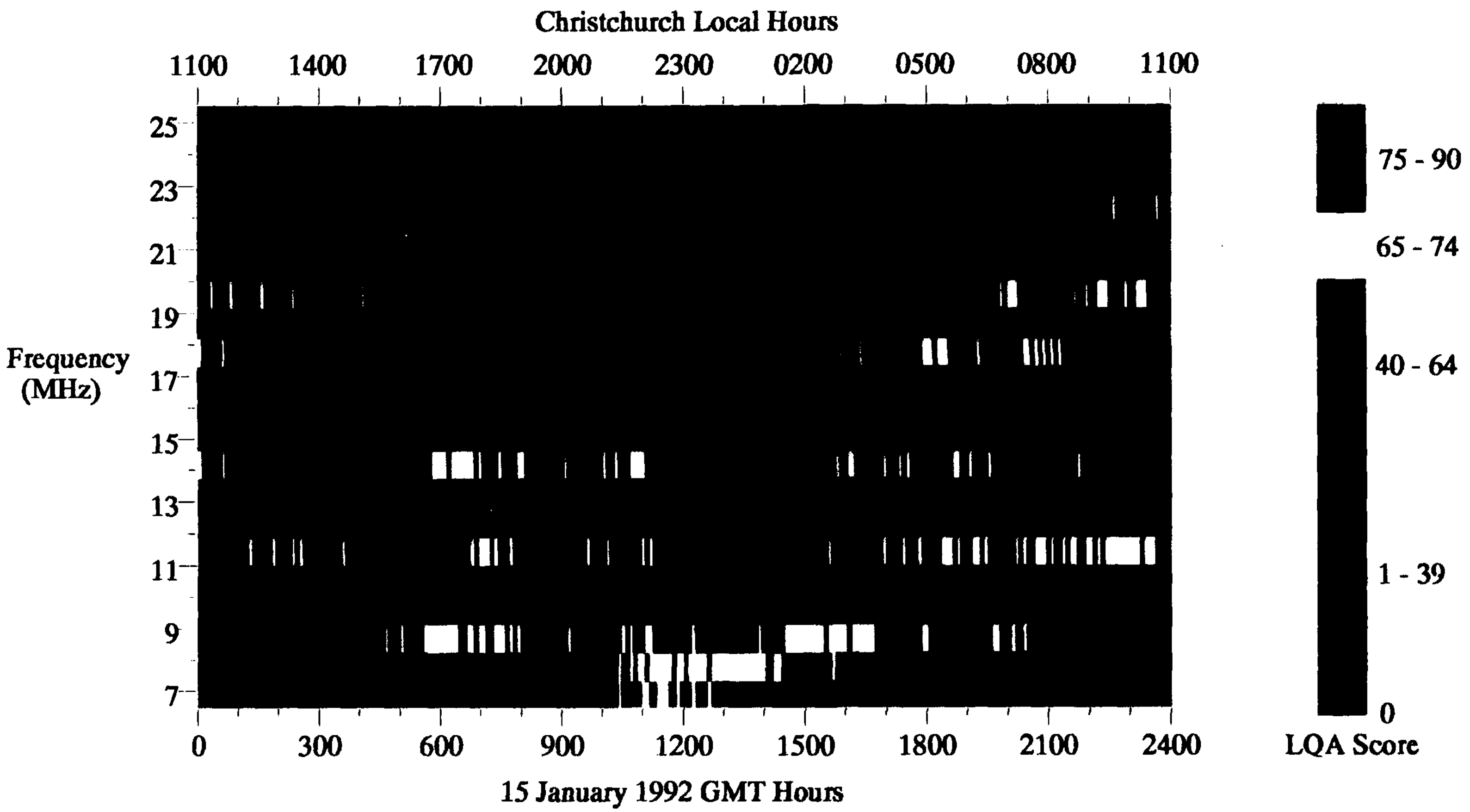

Figure A-3. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 15 January 1992

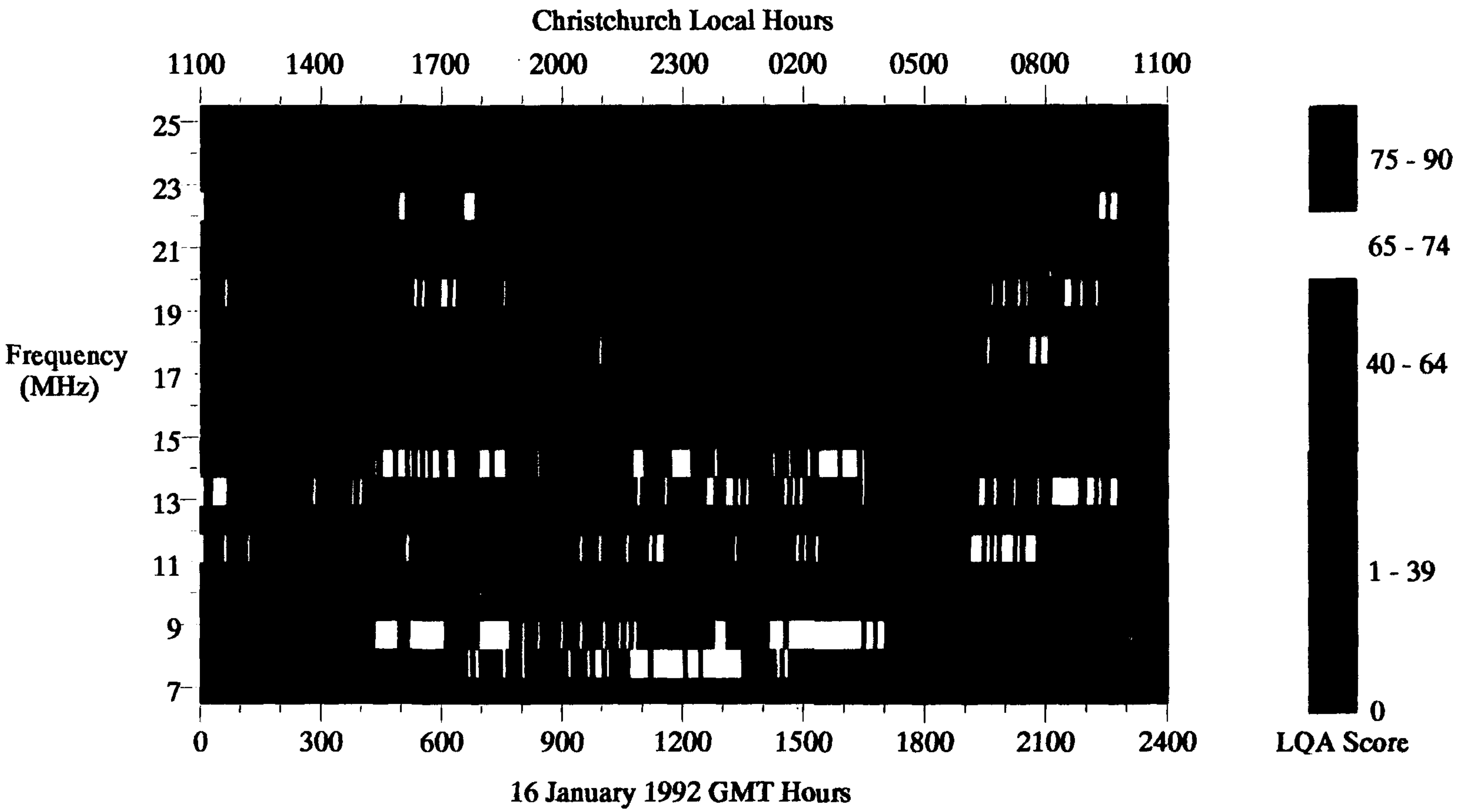

Figure A-4. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 16 January 1992

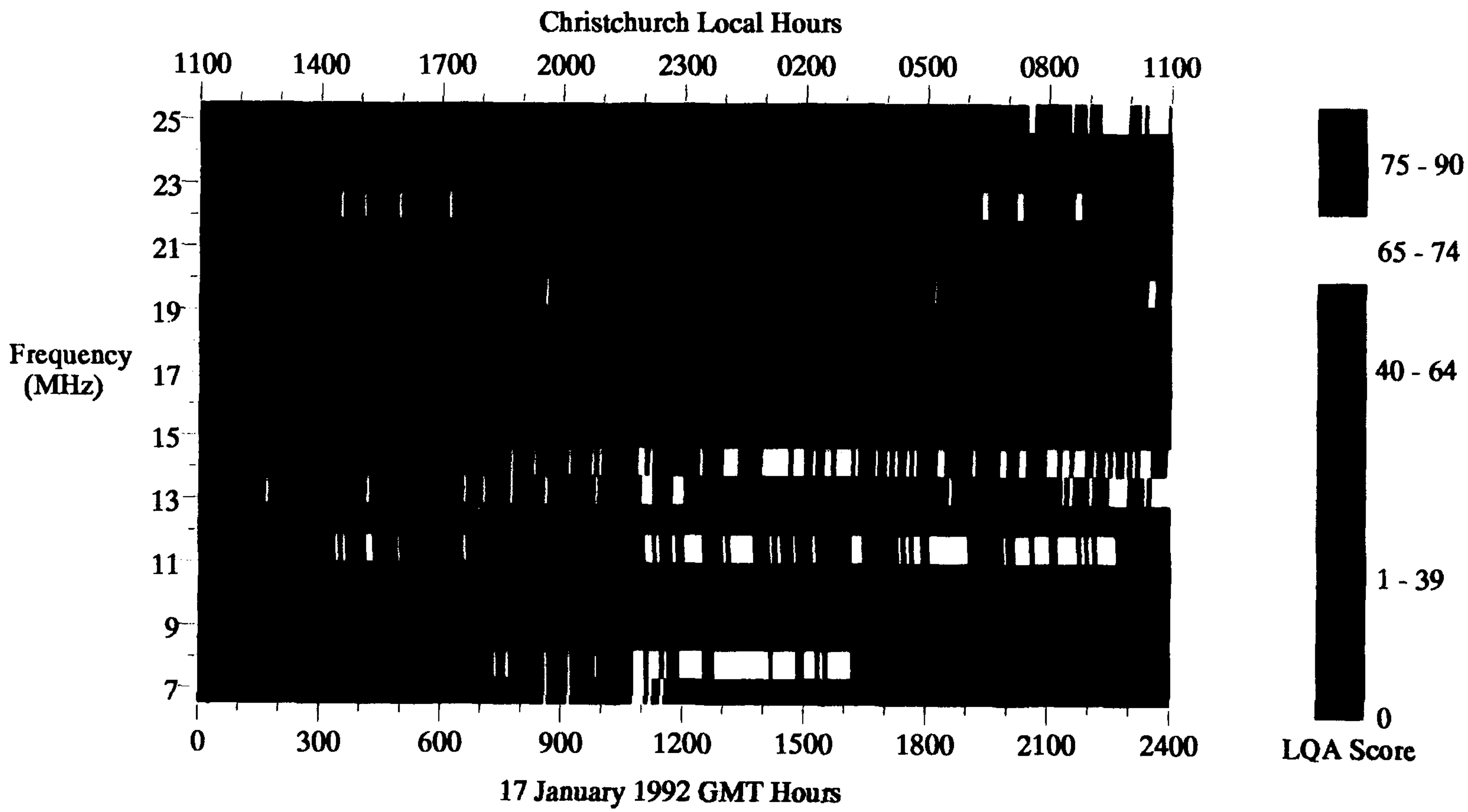

Figure A-5. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 17 January 1992

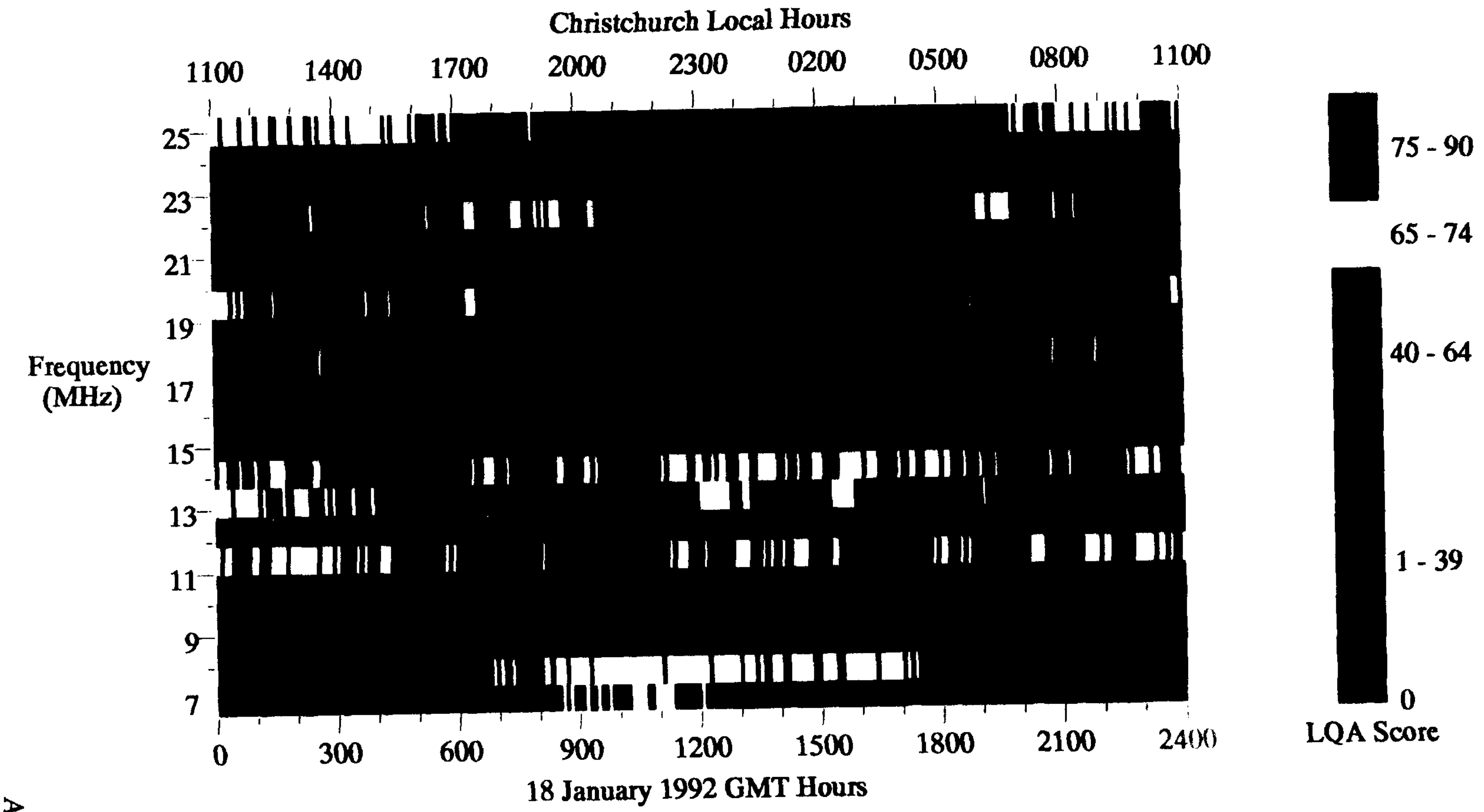

Figure A-6. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 18 January 1992

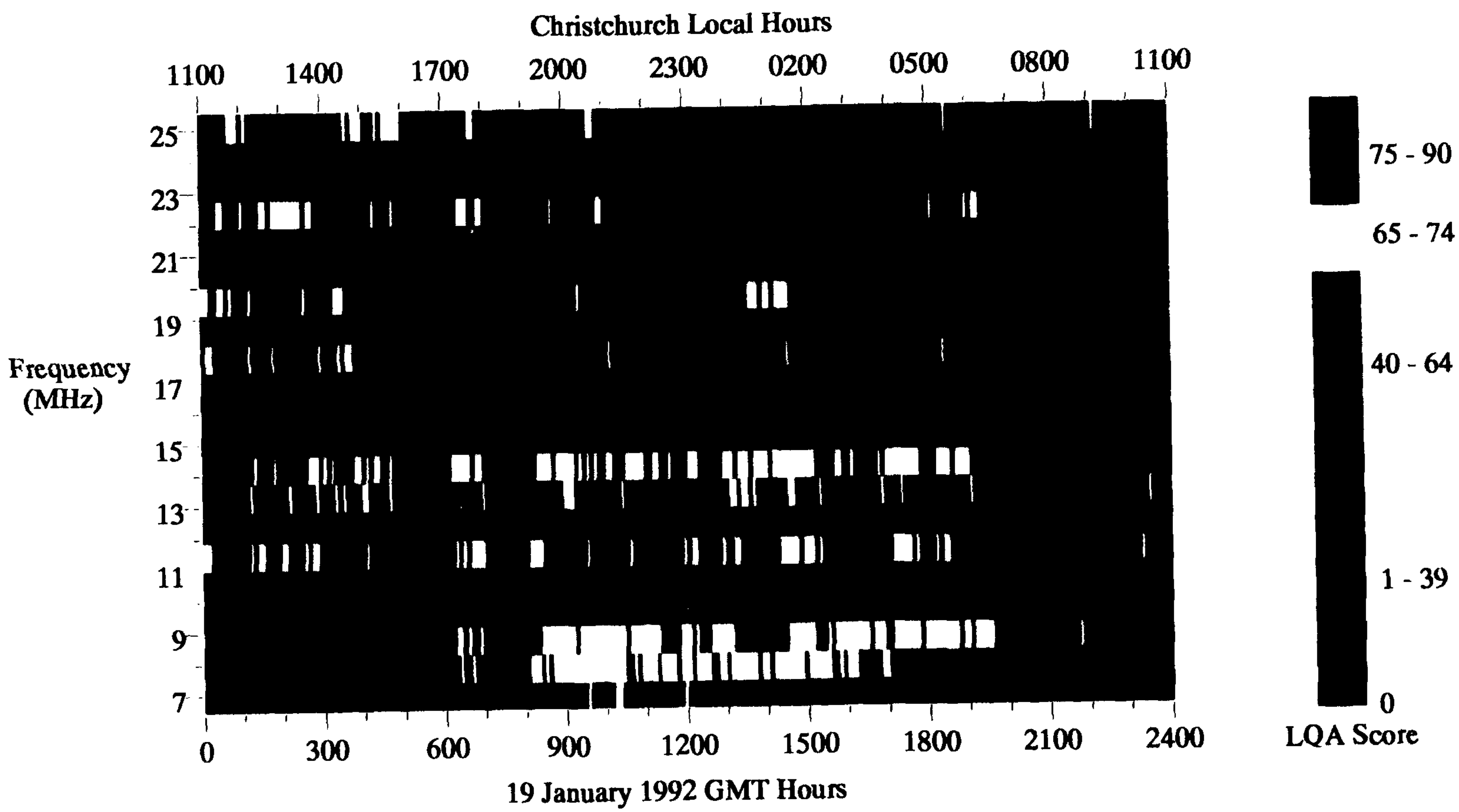

Figure A-7. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 19 January 1992

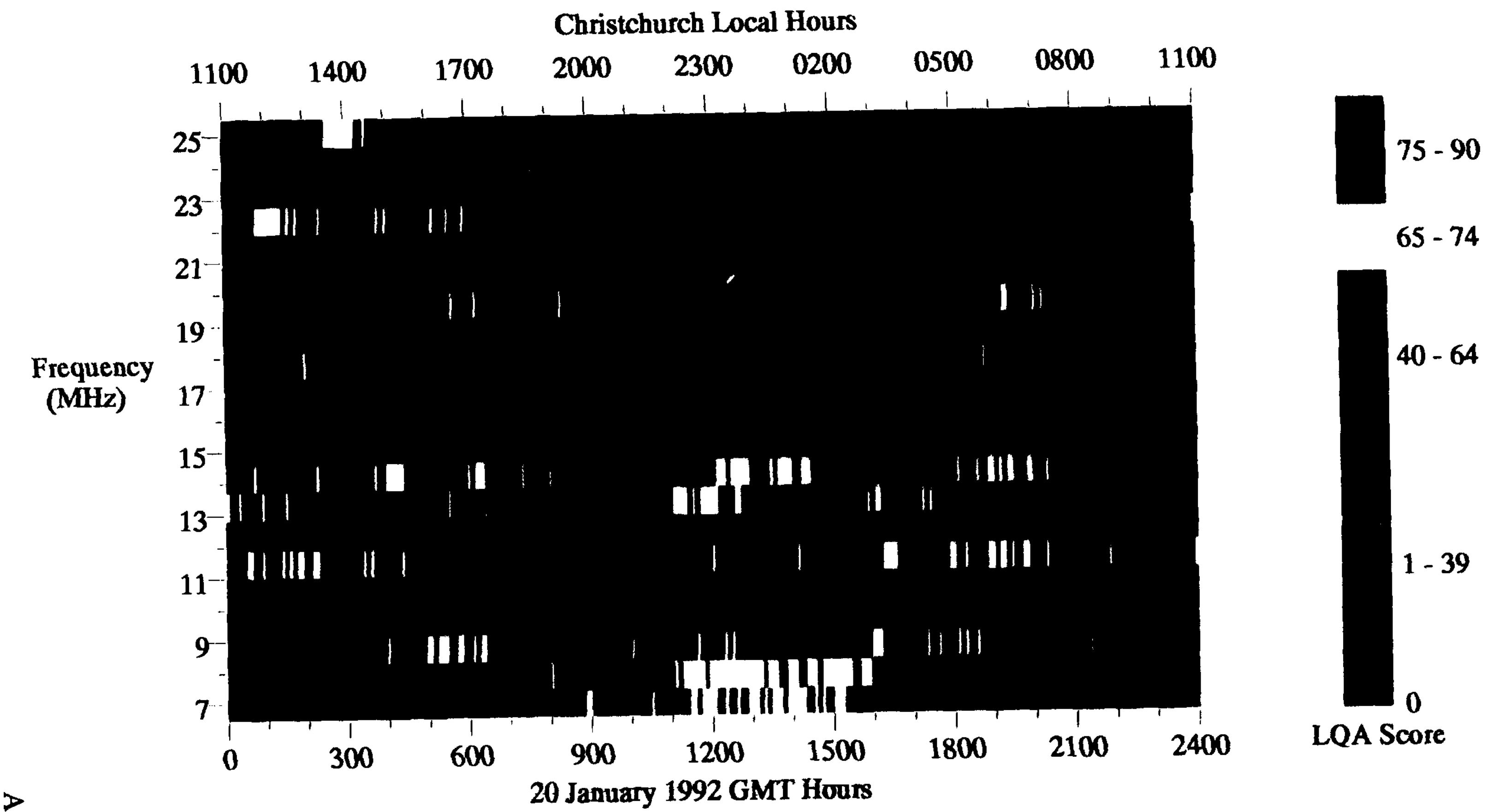

Figure A-8. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 20 January 1992

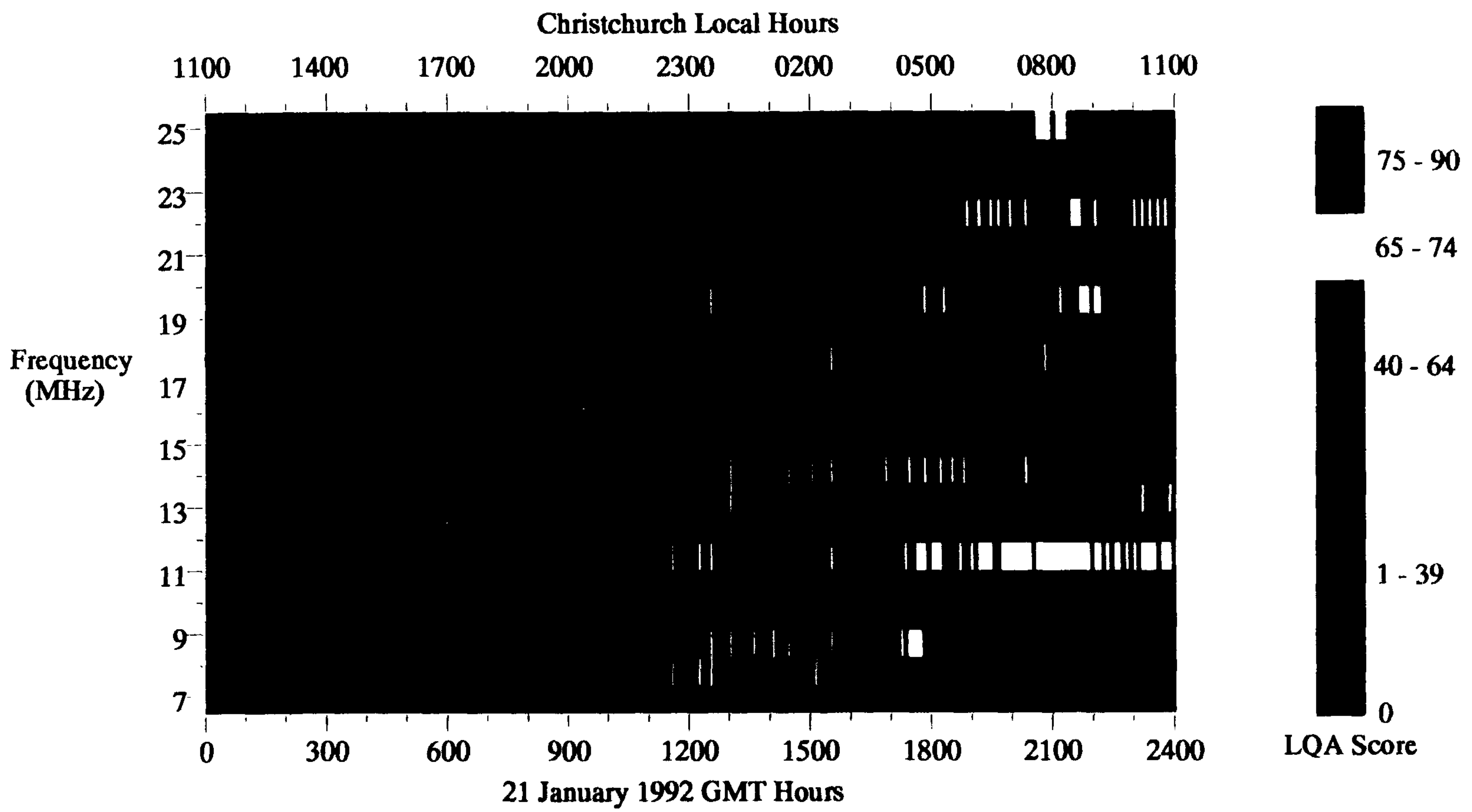

Figure A-9. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 21 January 1992

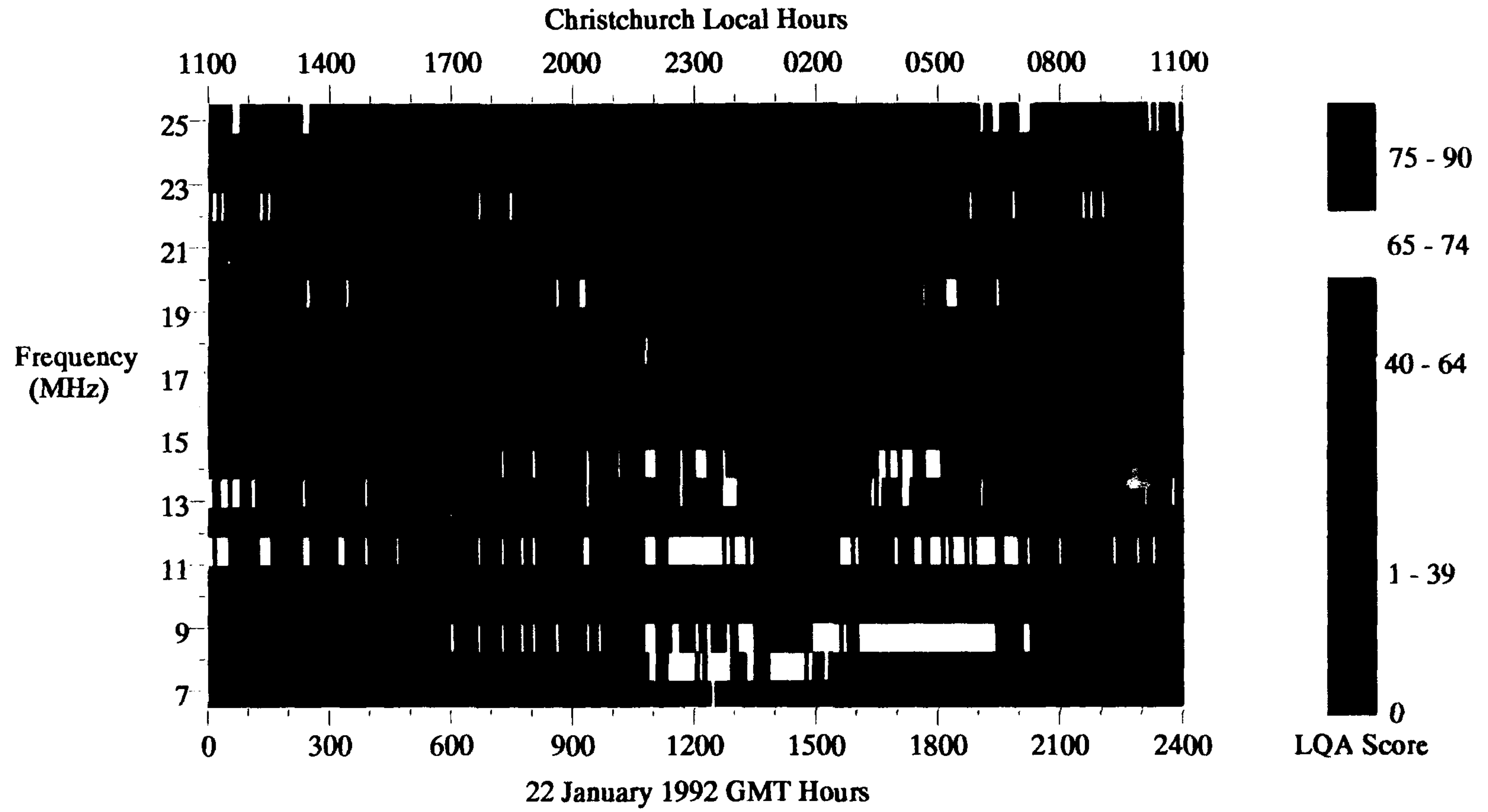

Figure A-10. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 22 January 1992

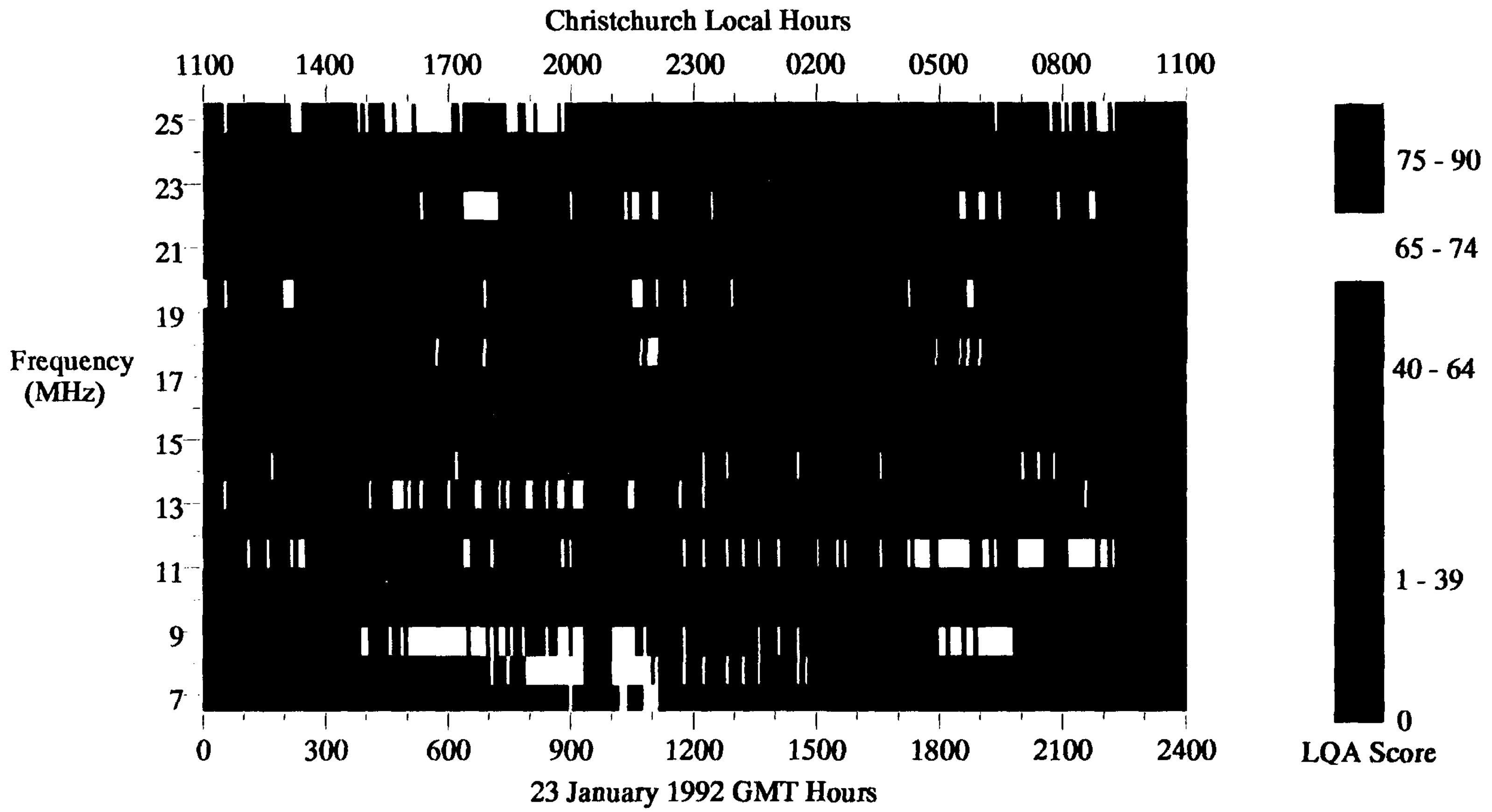

Figure A-11. Link Quality Analysis Score Between Christchurch, NZ, and Black Island, Antarctica, 23 January 1992

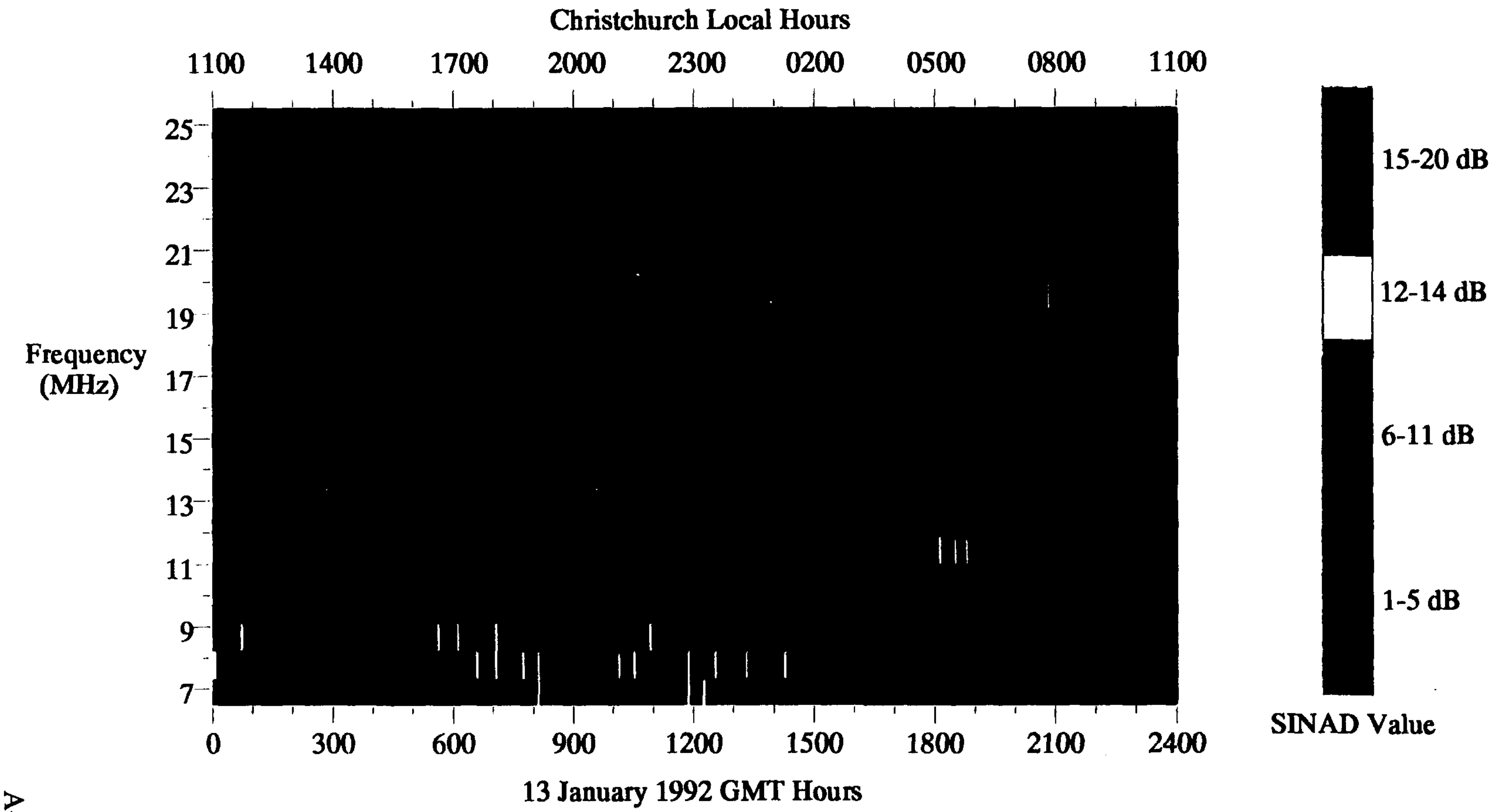

Figure A-12. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 13 January 1992

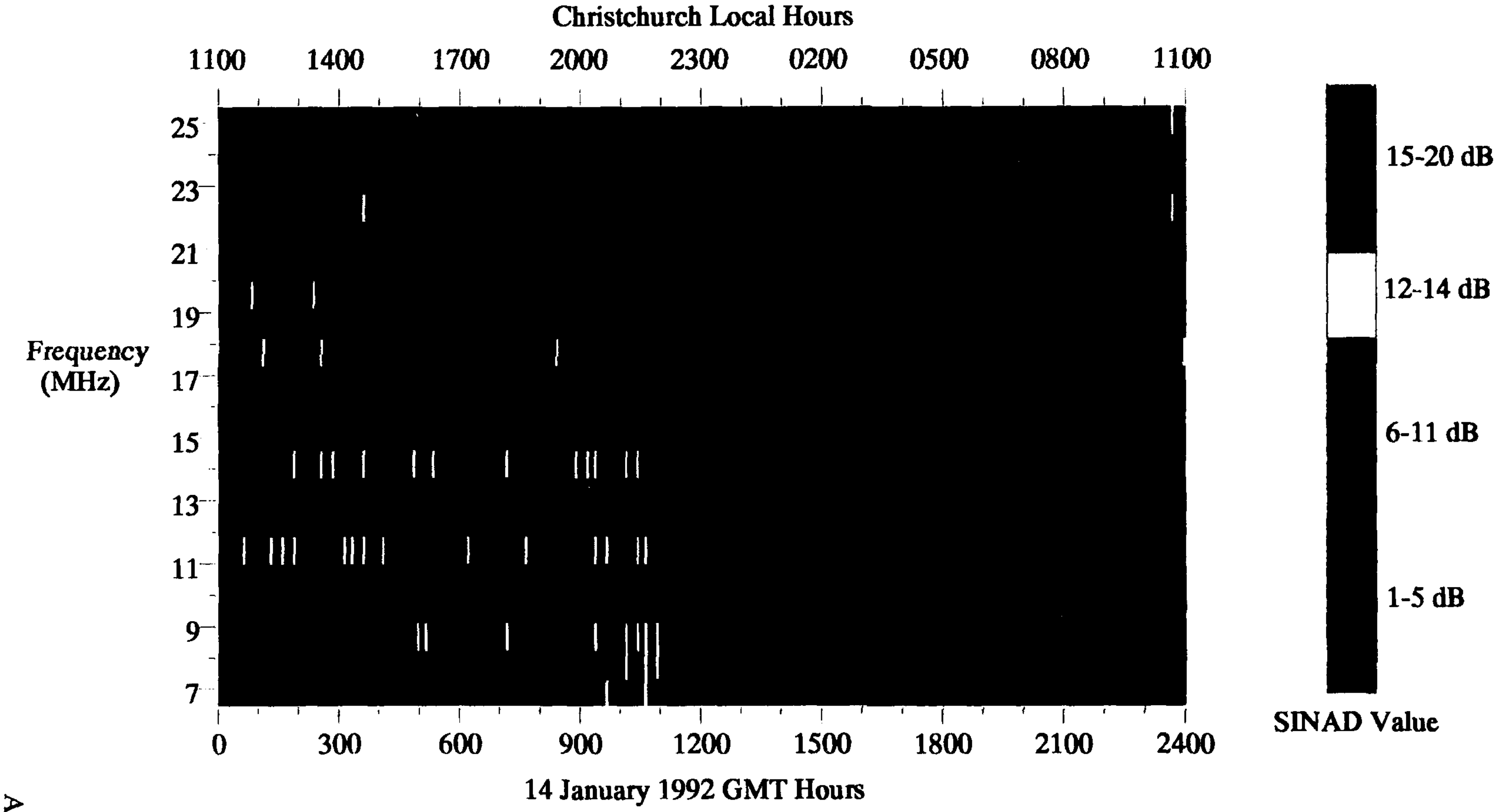

Figure A-13. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 14 January 1992

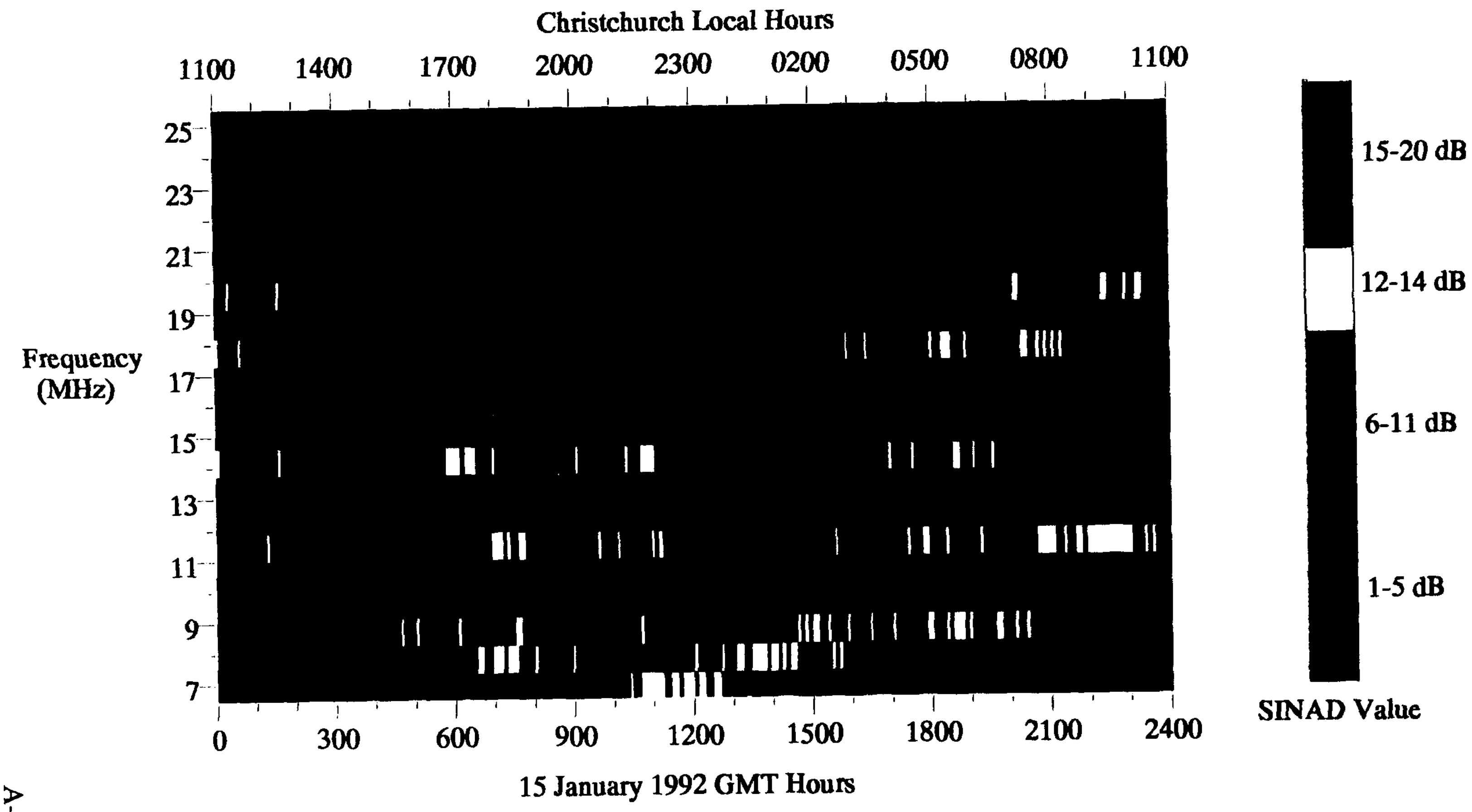

Figure A-14. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 15 January 1992

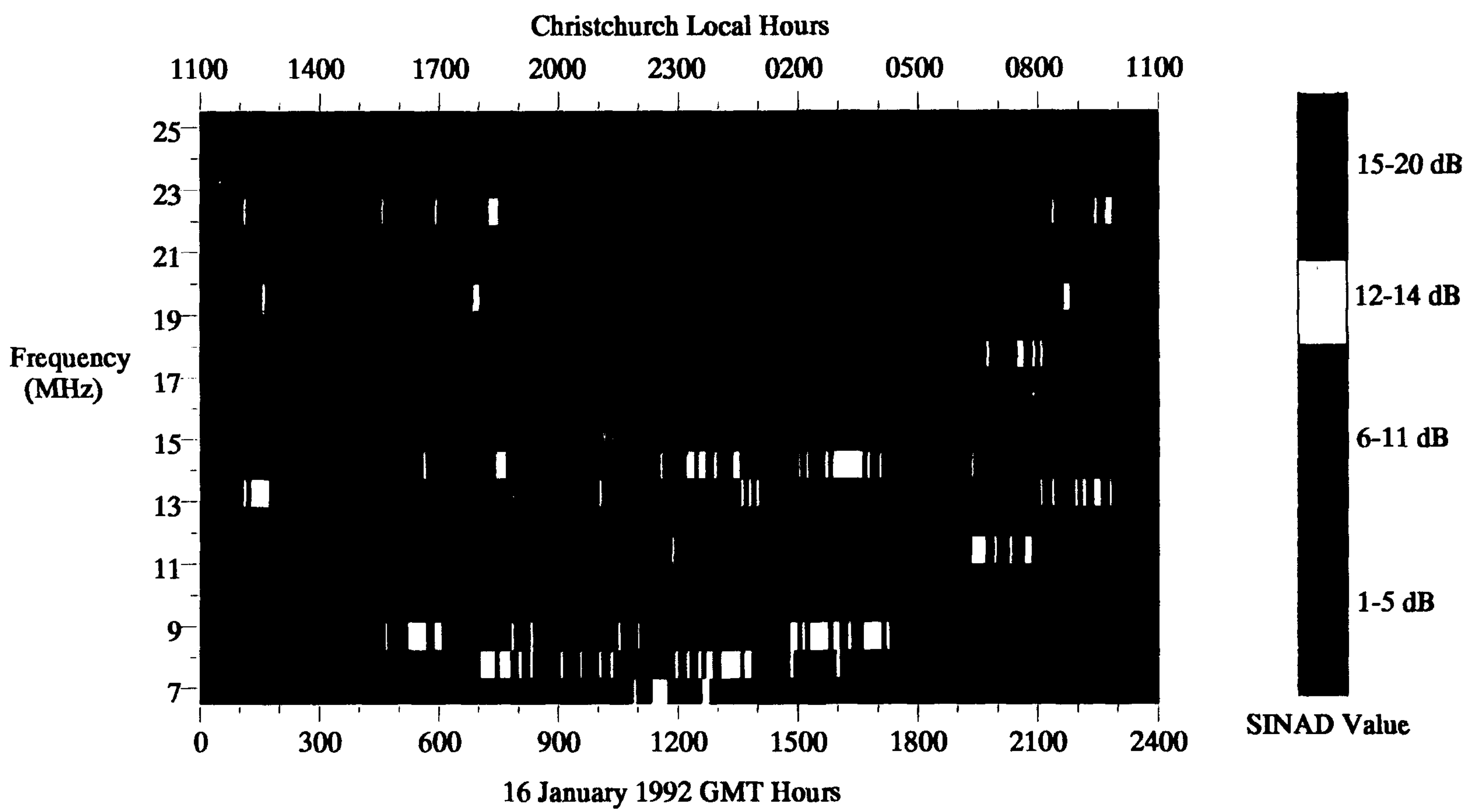

Figure A-15. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 16 January 1992

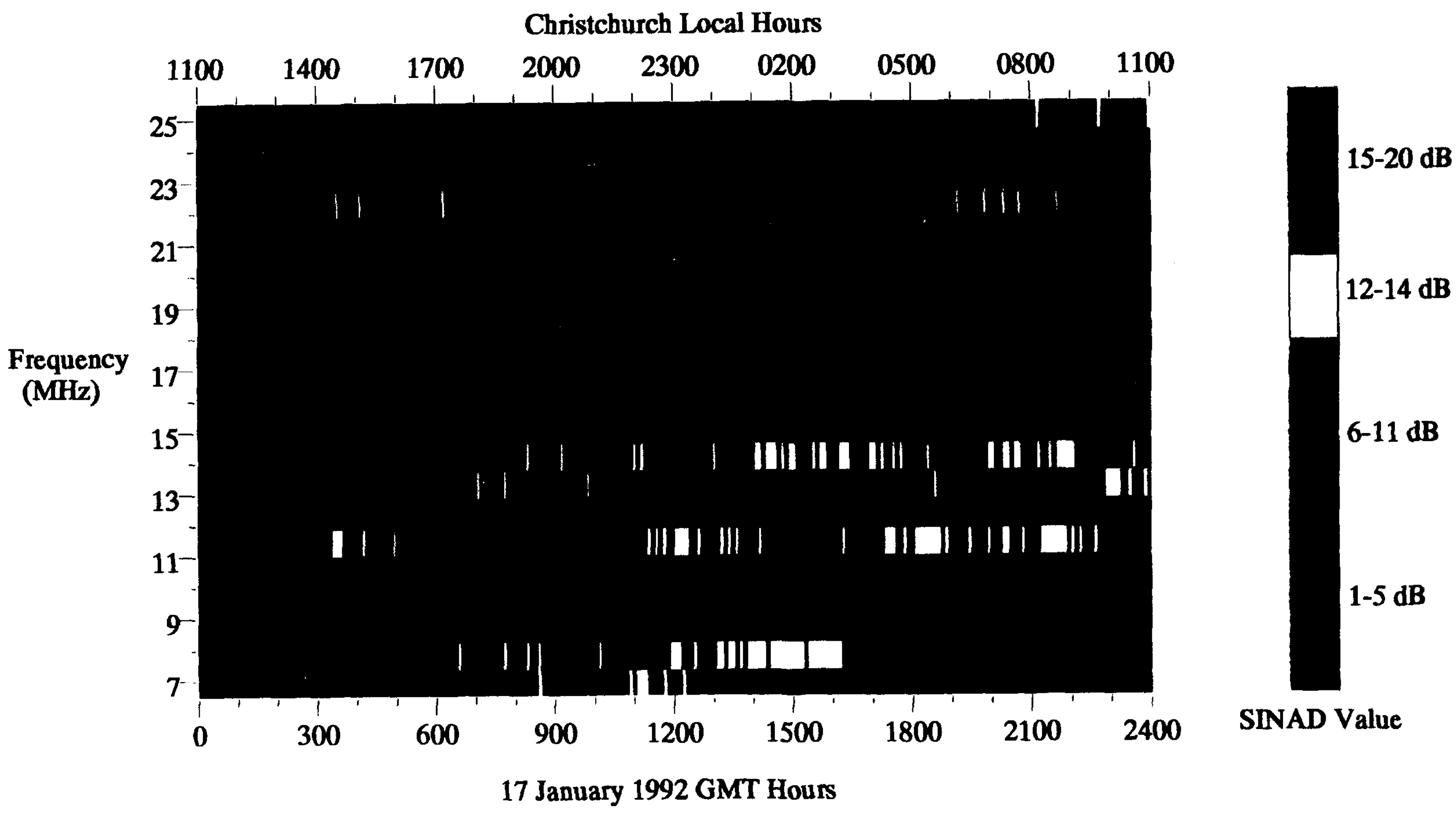

Figure A-16. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 17 January 1992

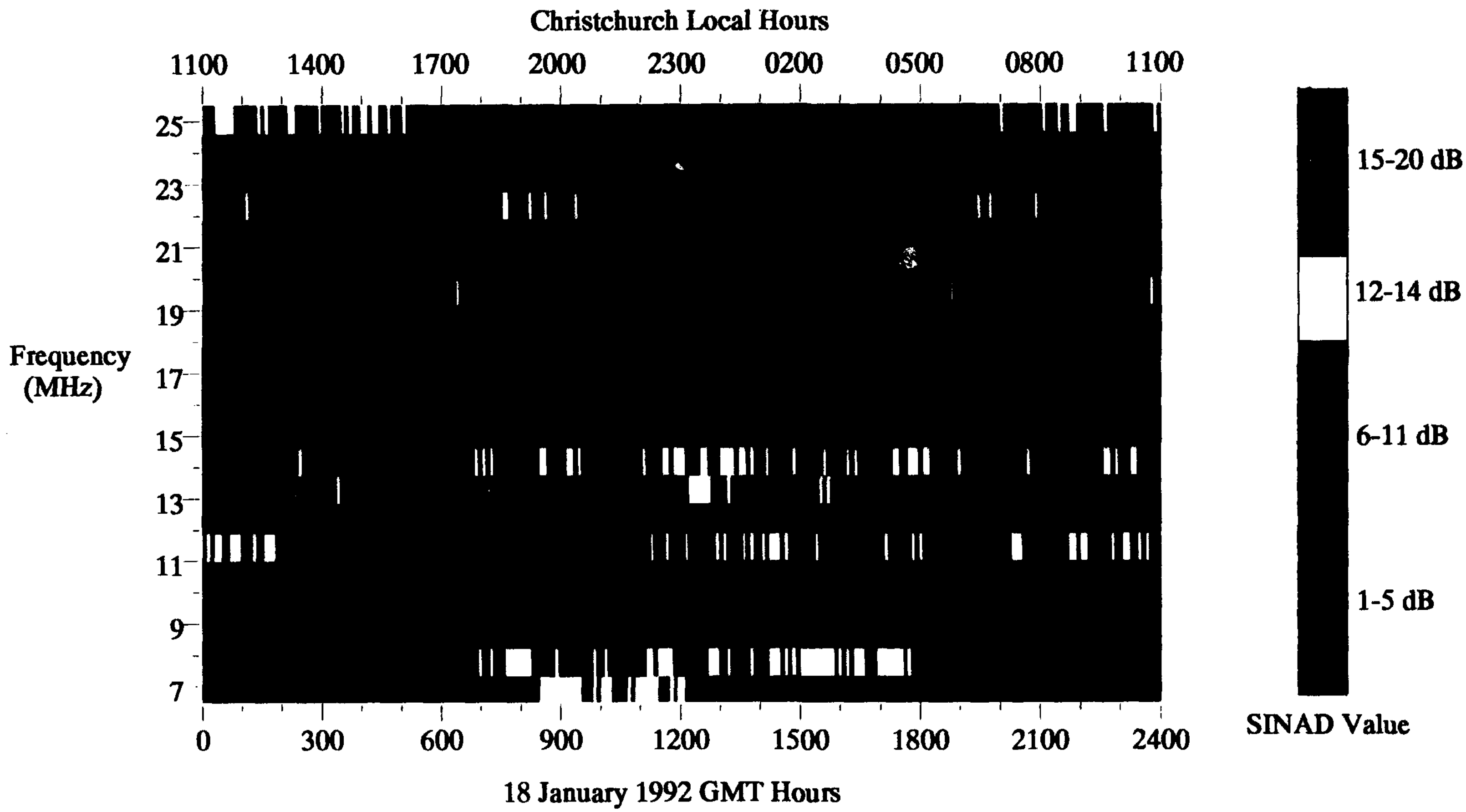

Figure A-17. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 18 January 1992

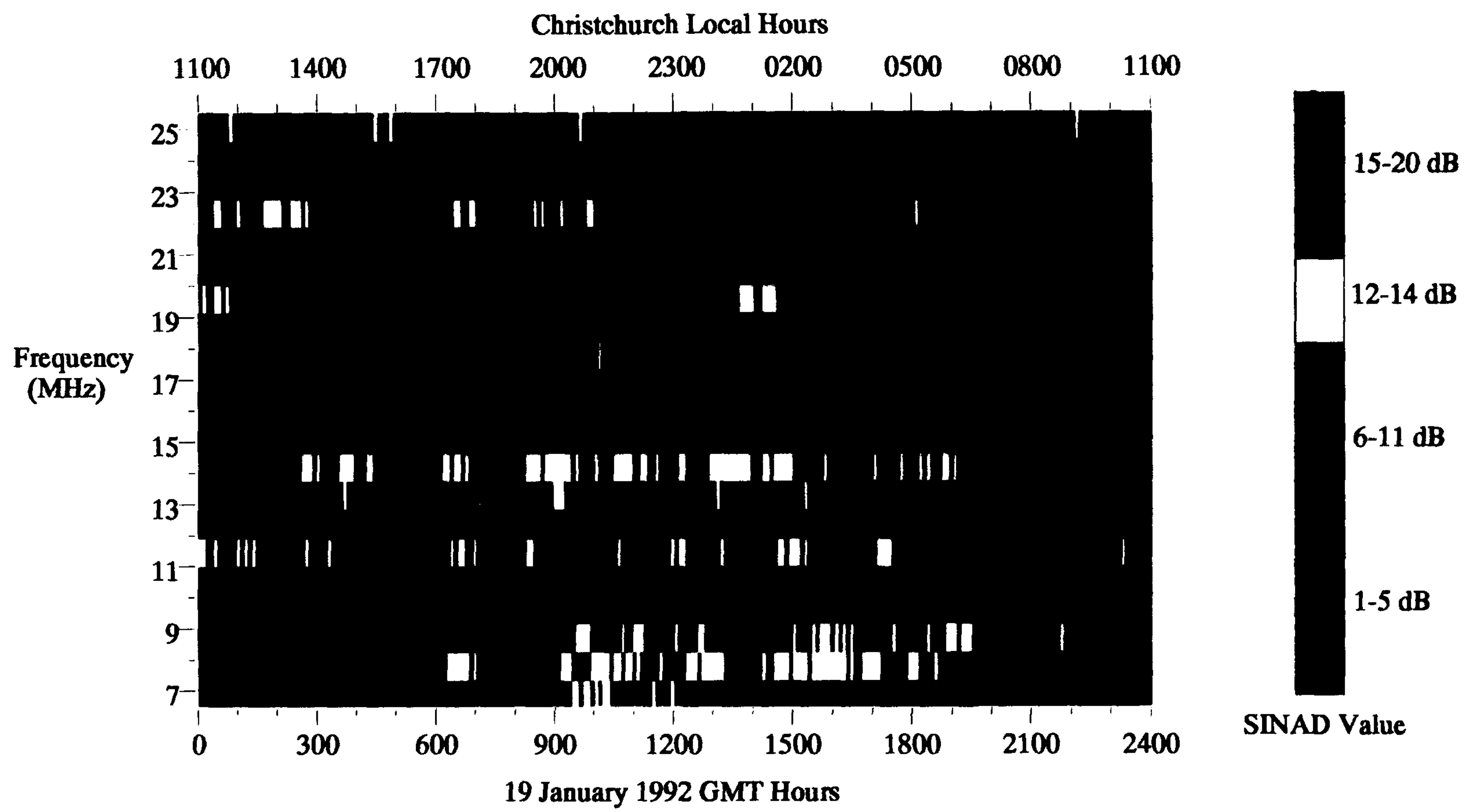

Figure A-18. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 19 January 1992

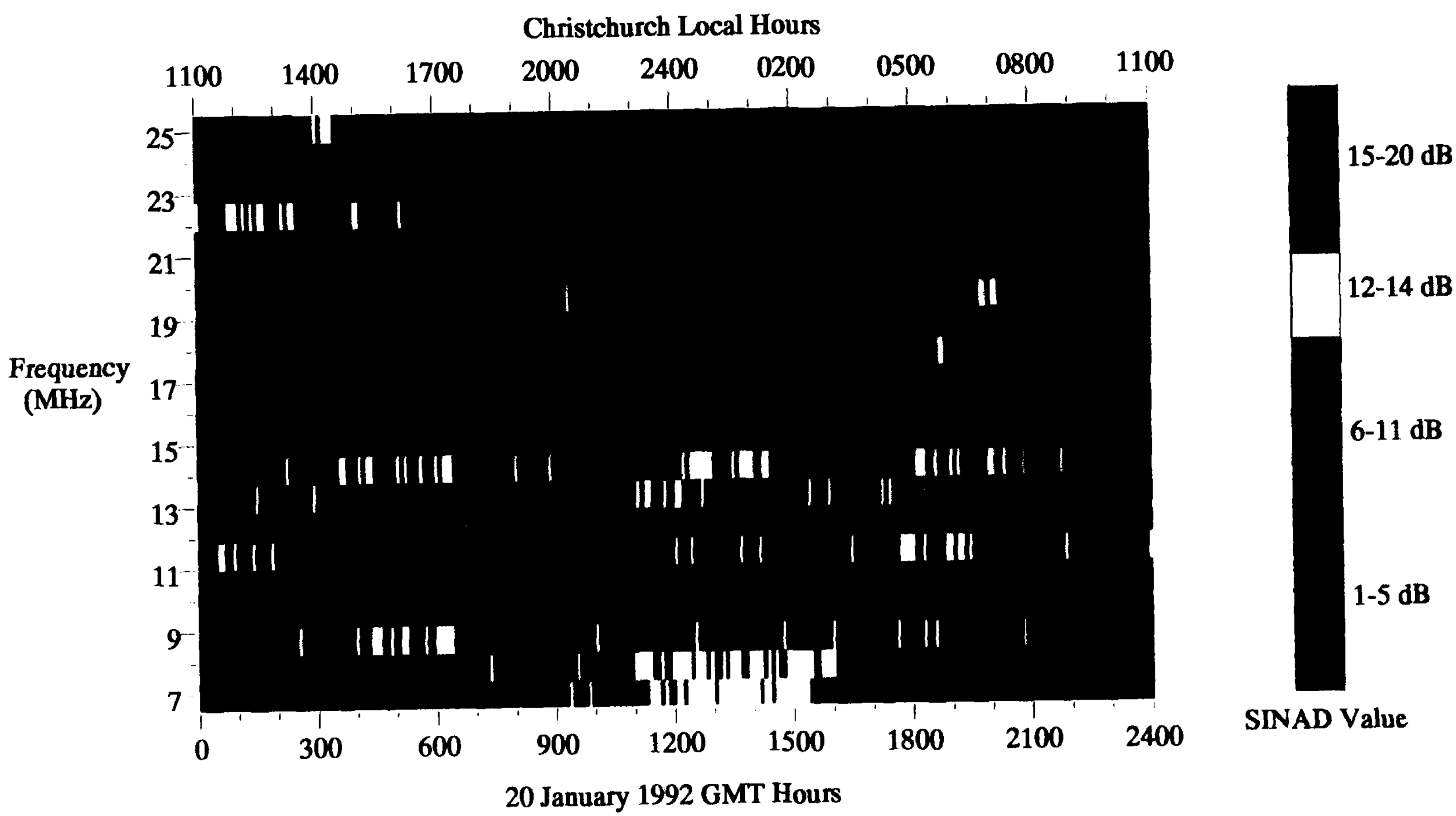

Figure A-19. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 20 January 1992

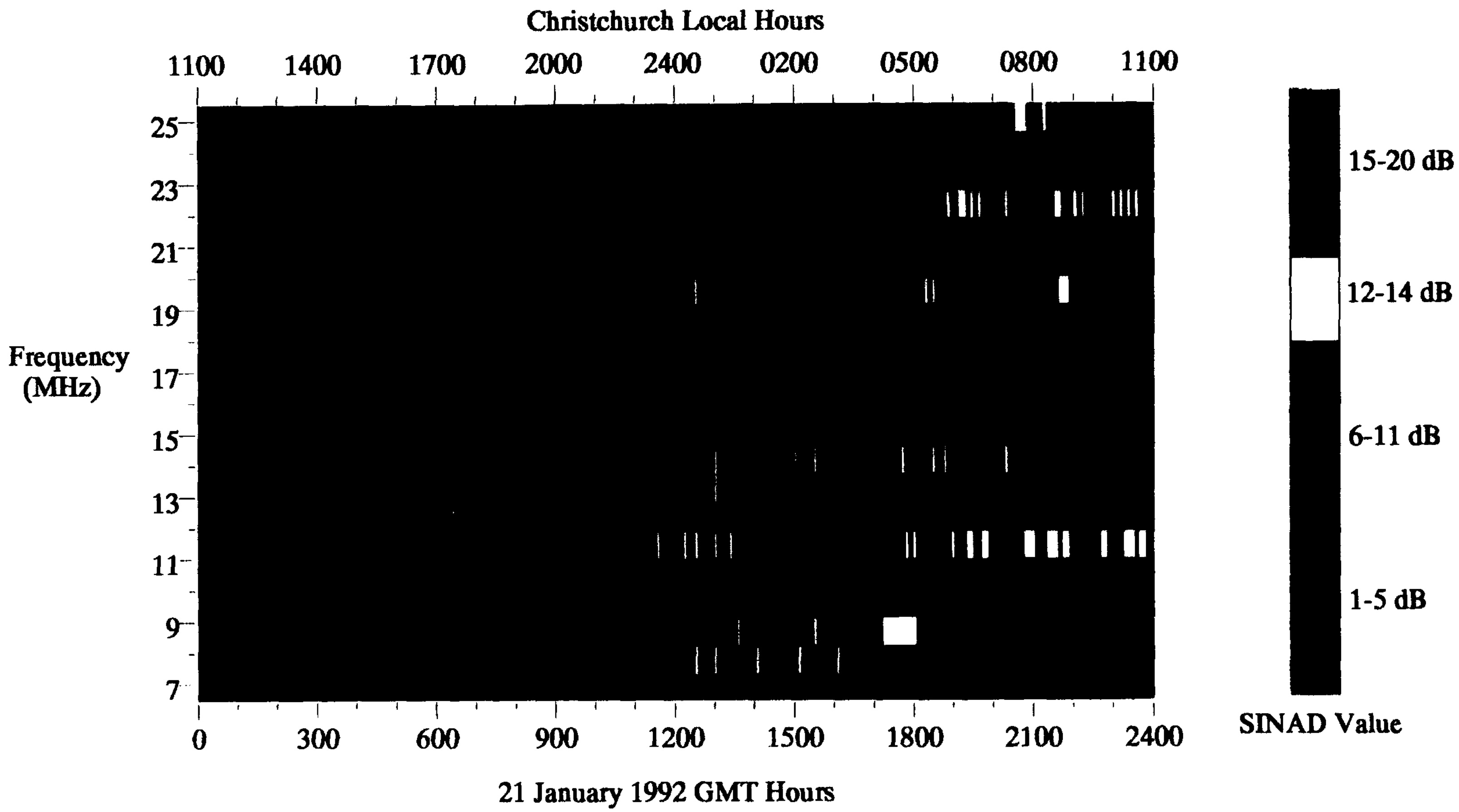

Figure A-20. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 21 January 1992

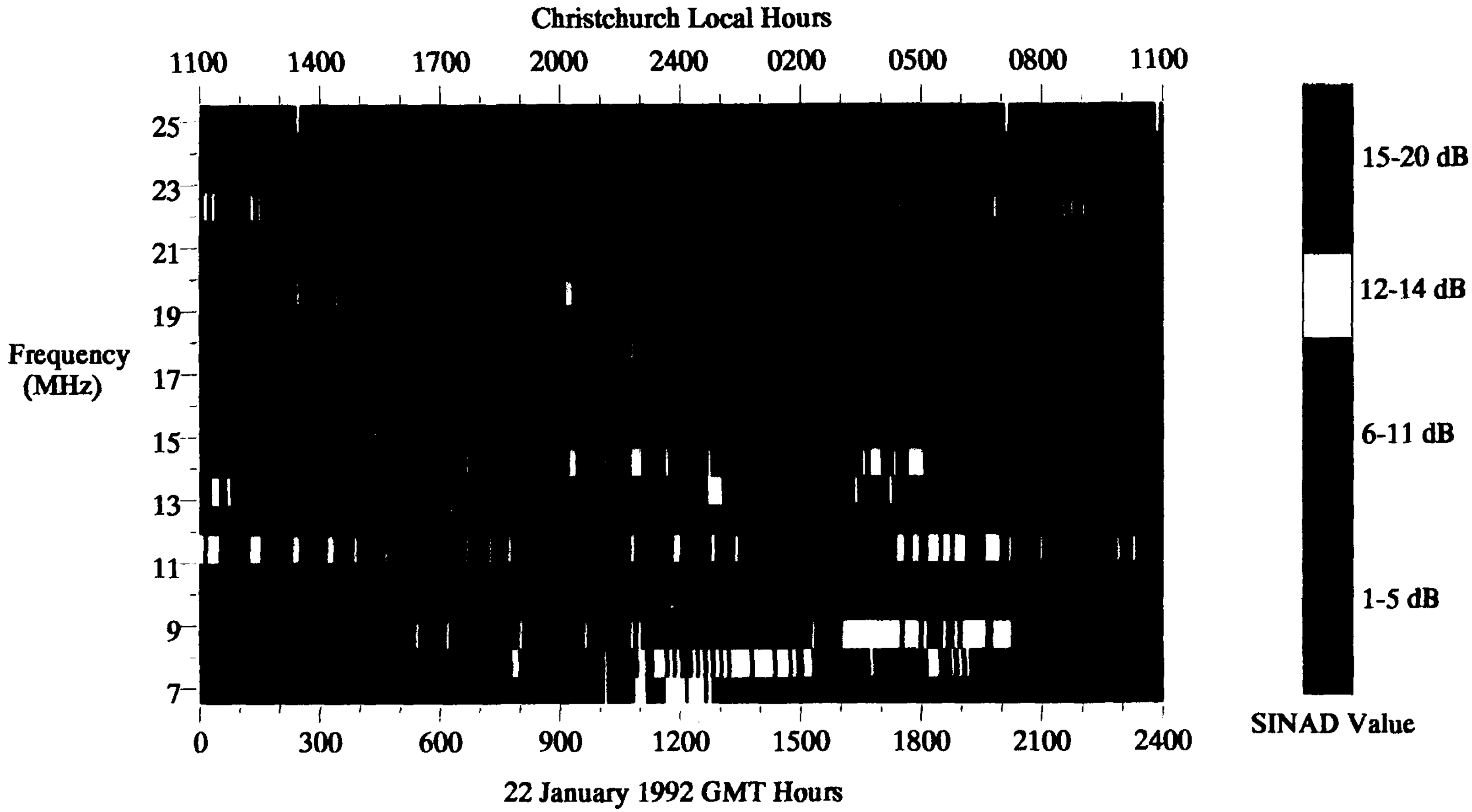

Figure A-21. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 22 January 1992

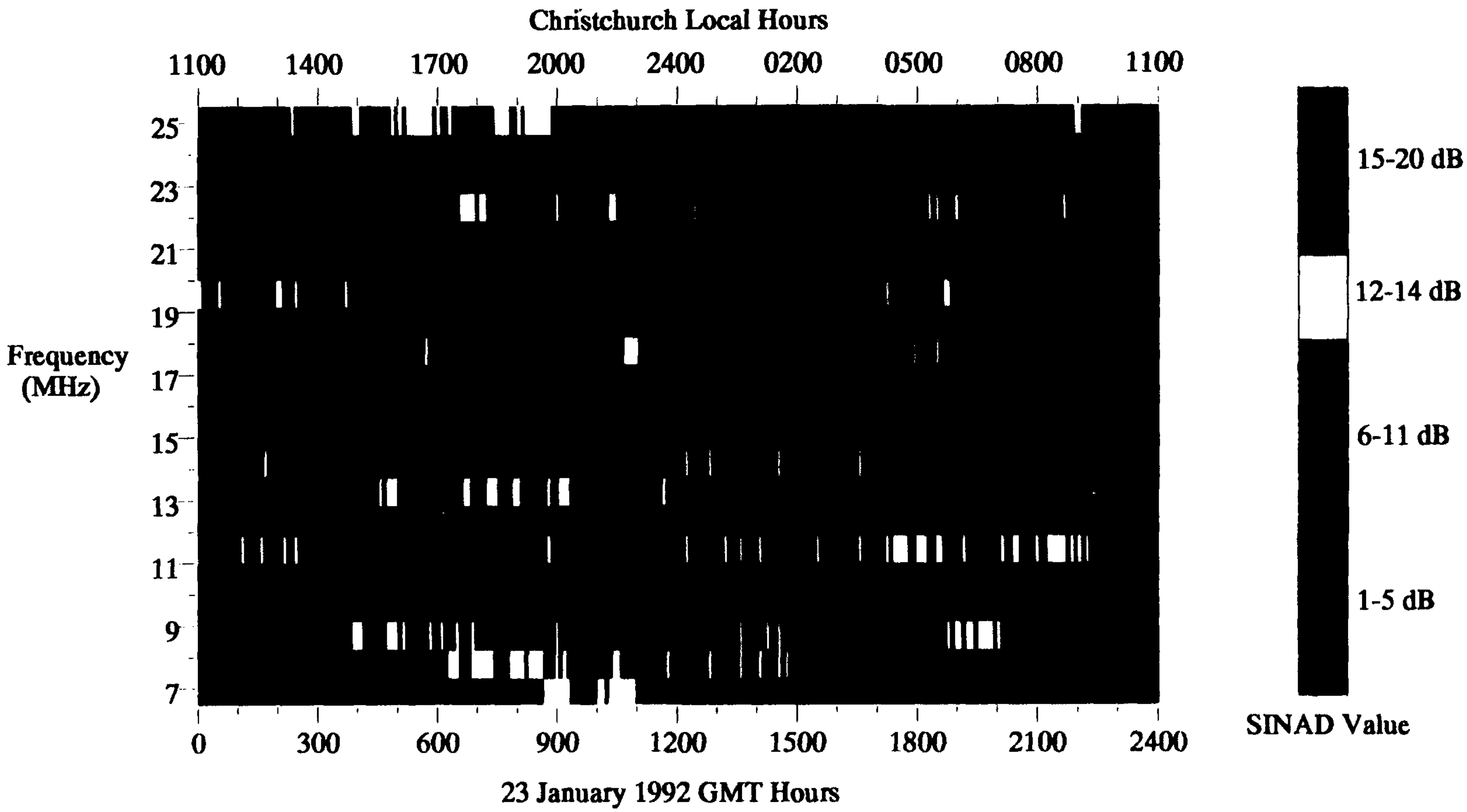

Figure A-22. SINAD Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 23 January 1992

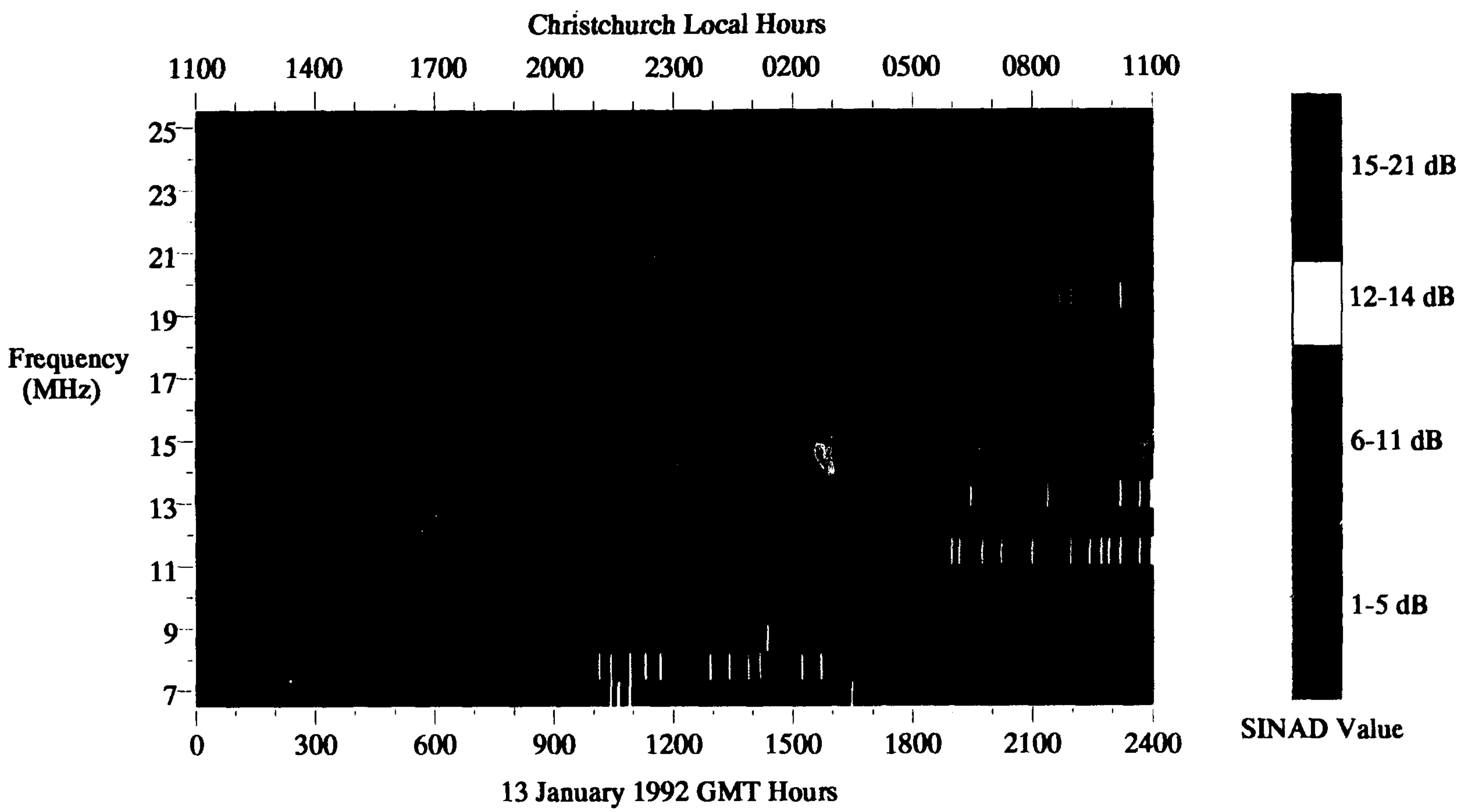

Figure A-23. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 13 January 1992

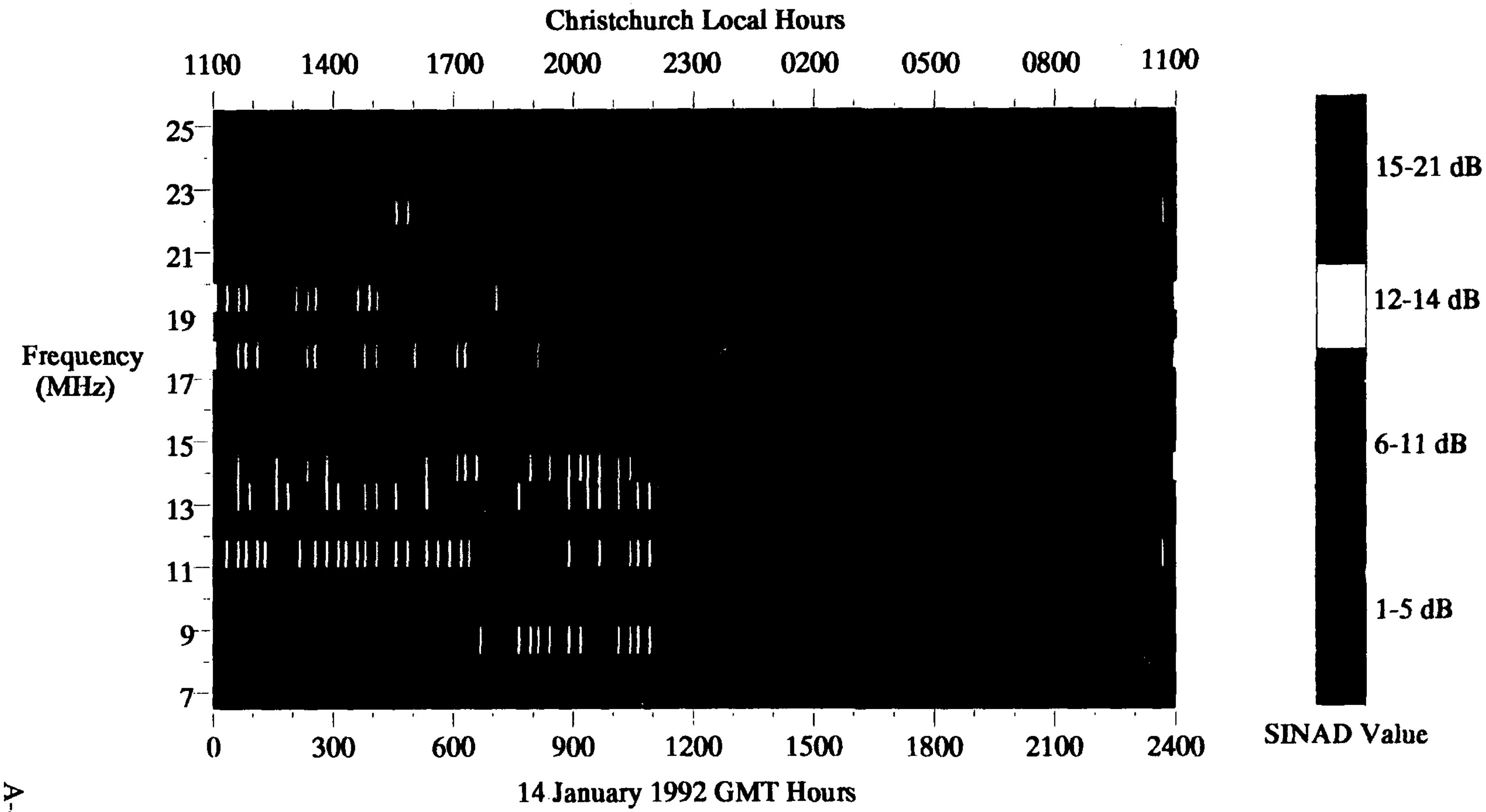

Figure A-24. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 14 January 1992

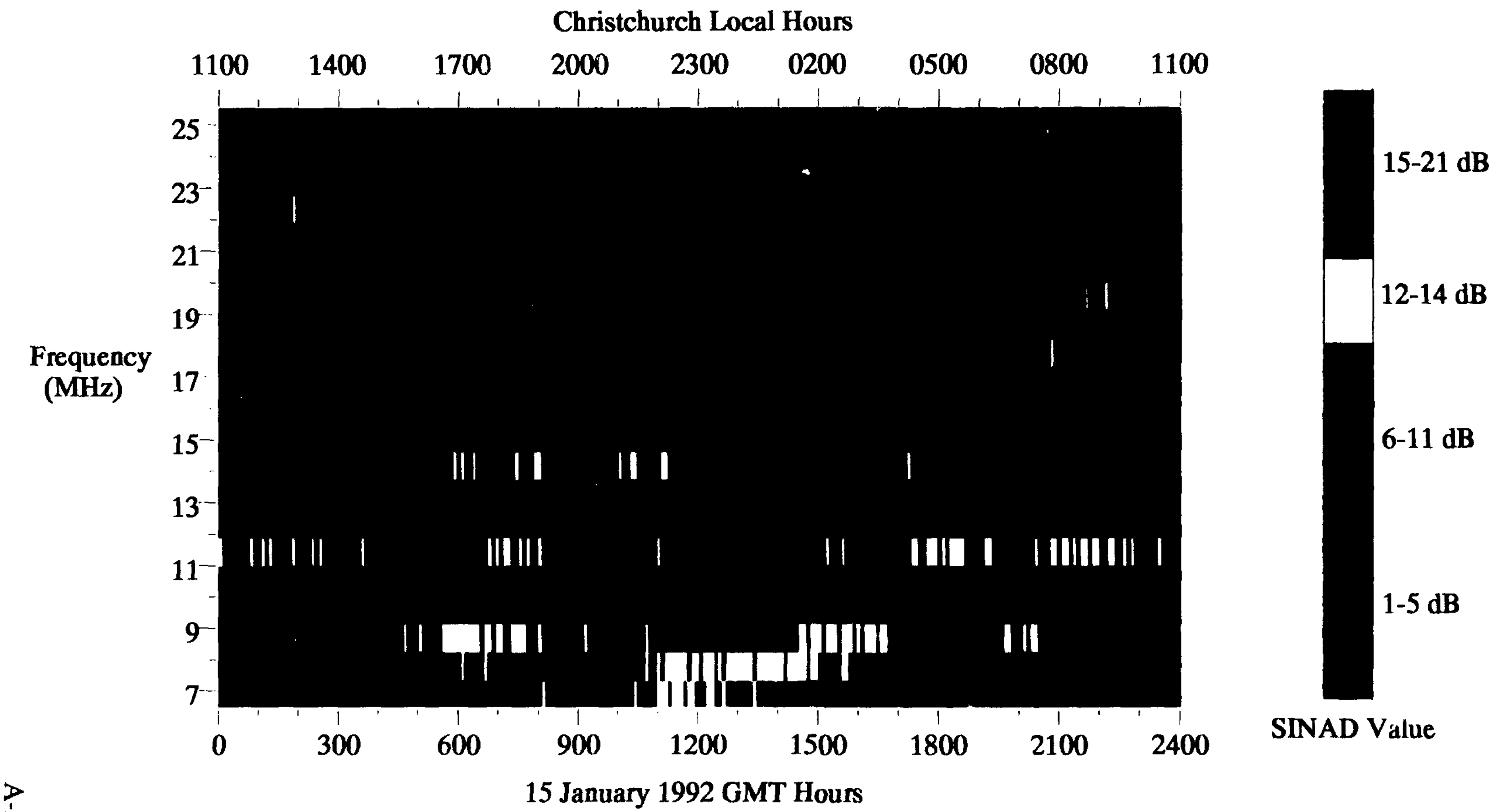

Figure A-25. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 15 January 1992

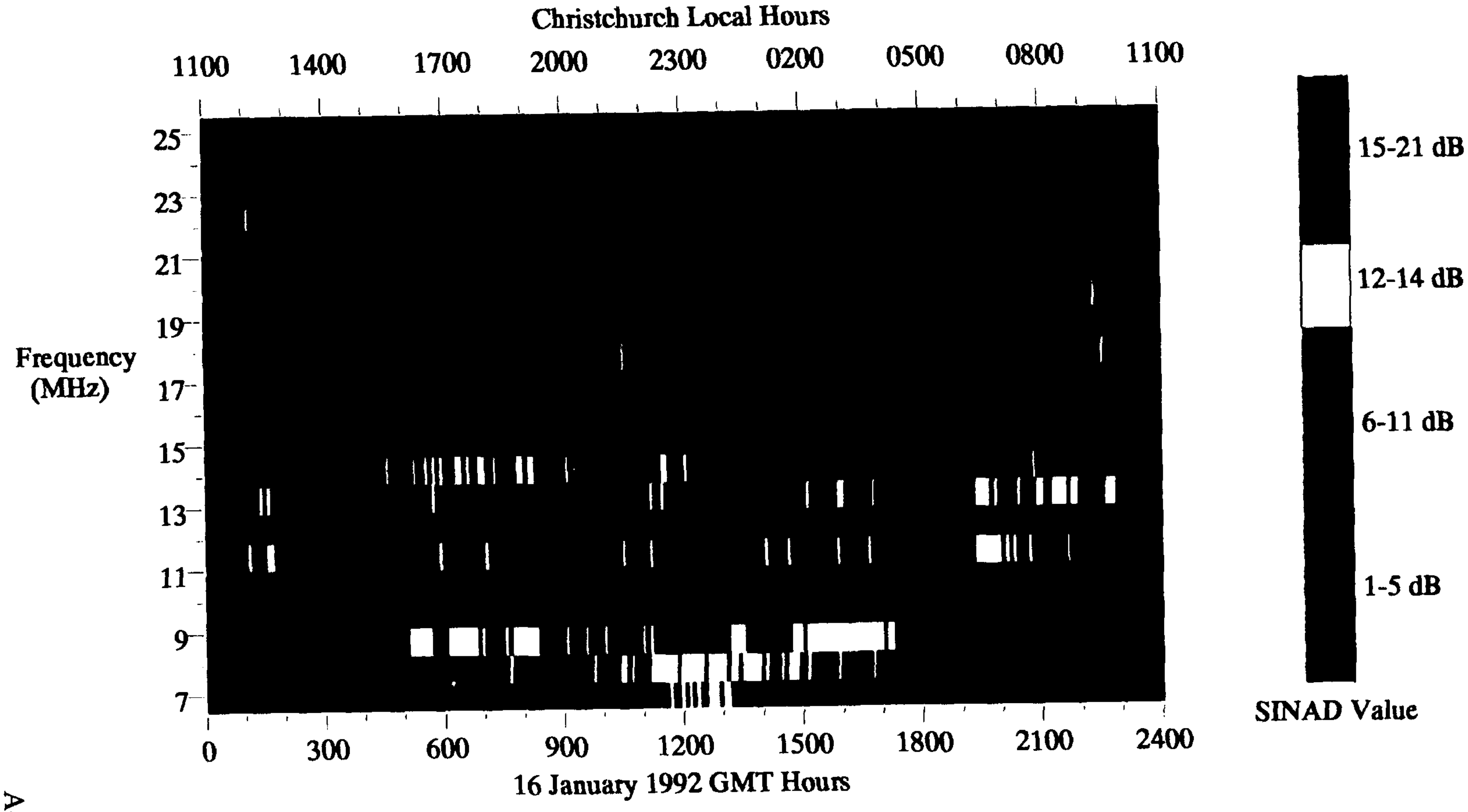

Figure A-26. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 16 January 1992

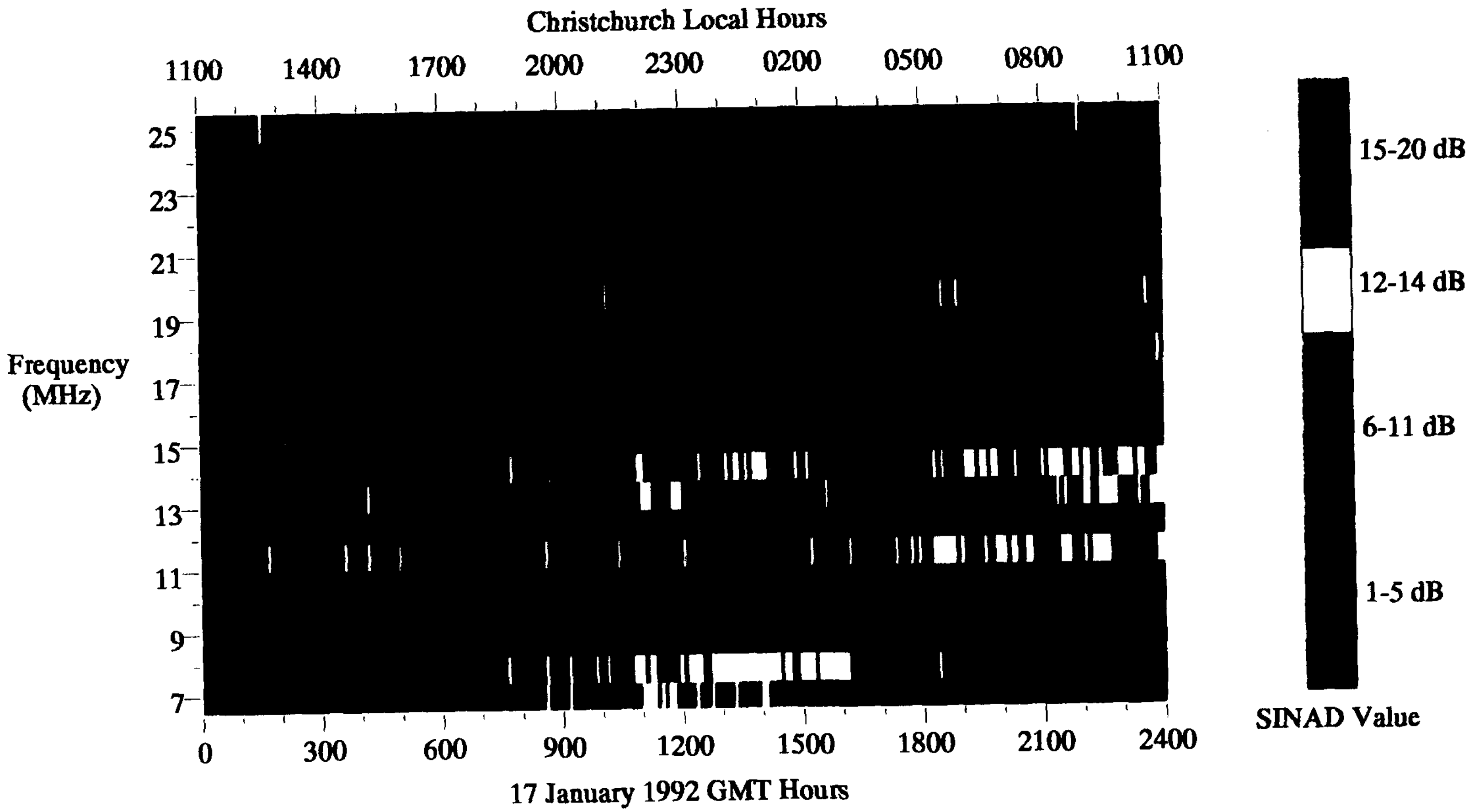

Figure A-27. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 17 January 1992

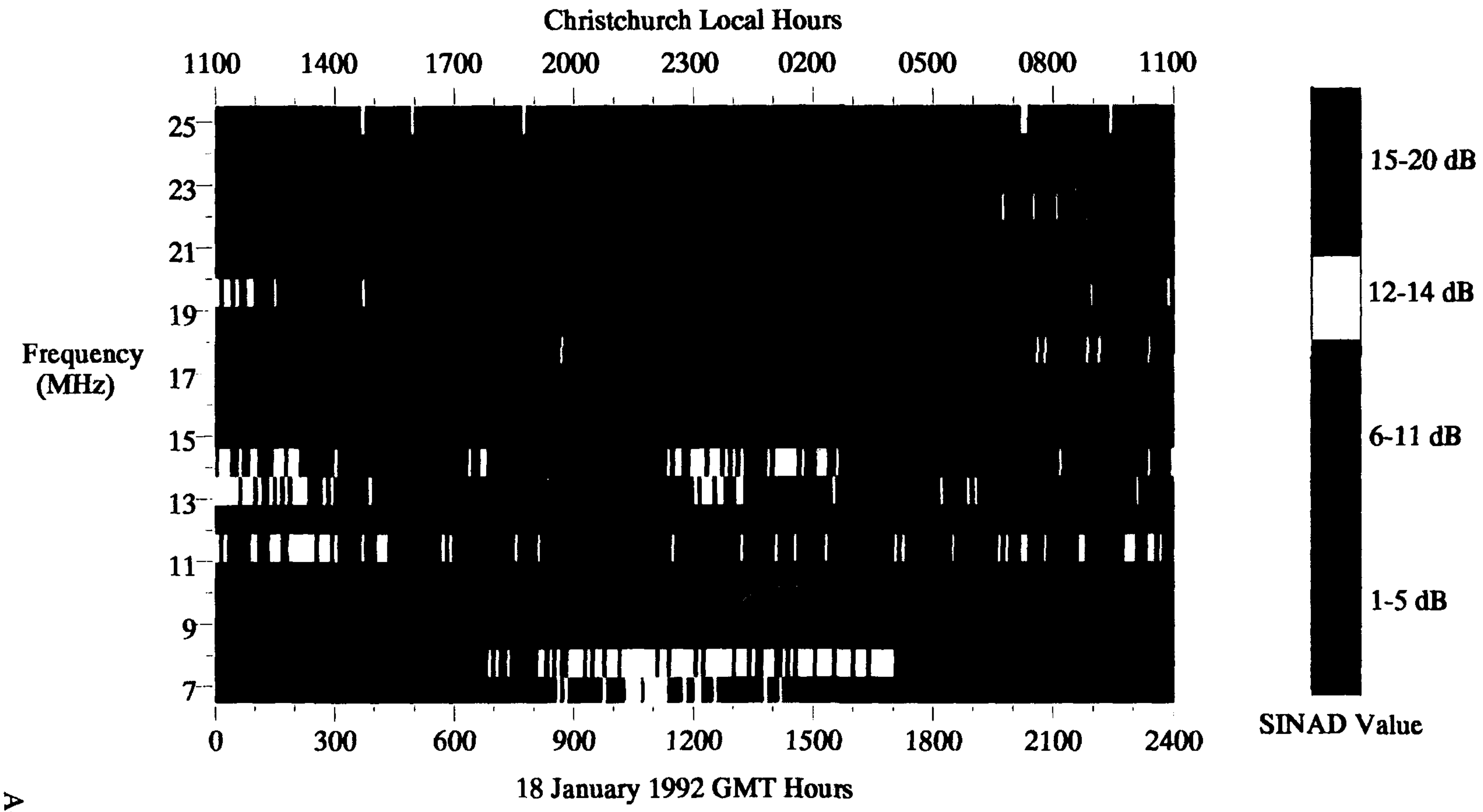

Figure A-28. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 18 January 1992

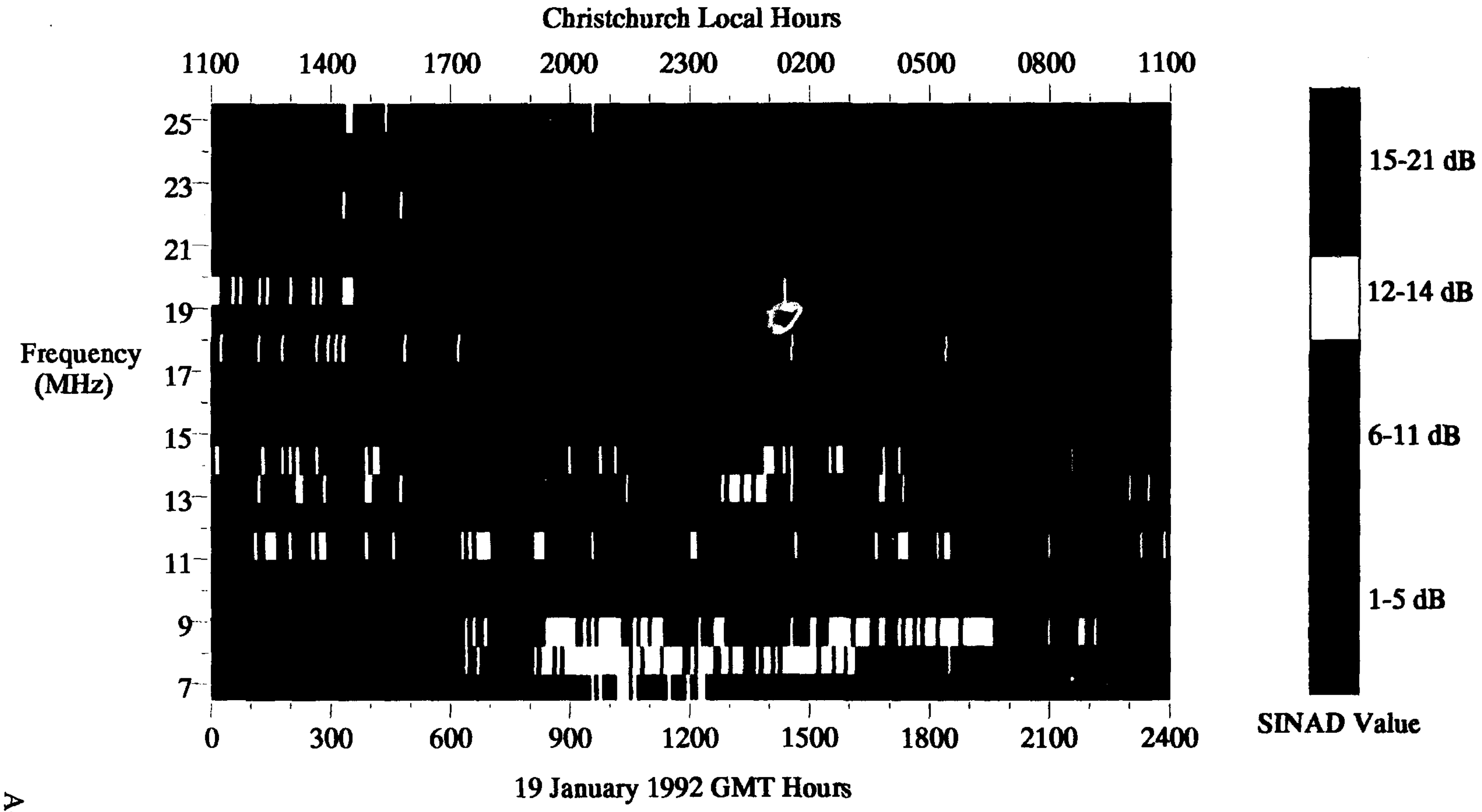

Figure A-29. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 19 January 1992

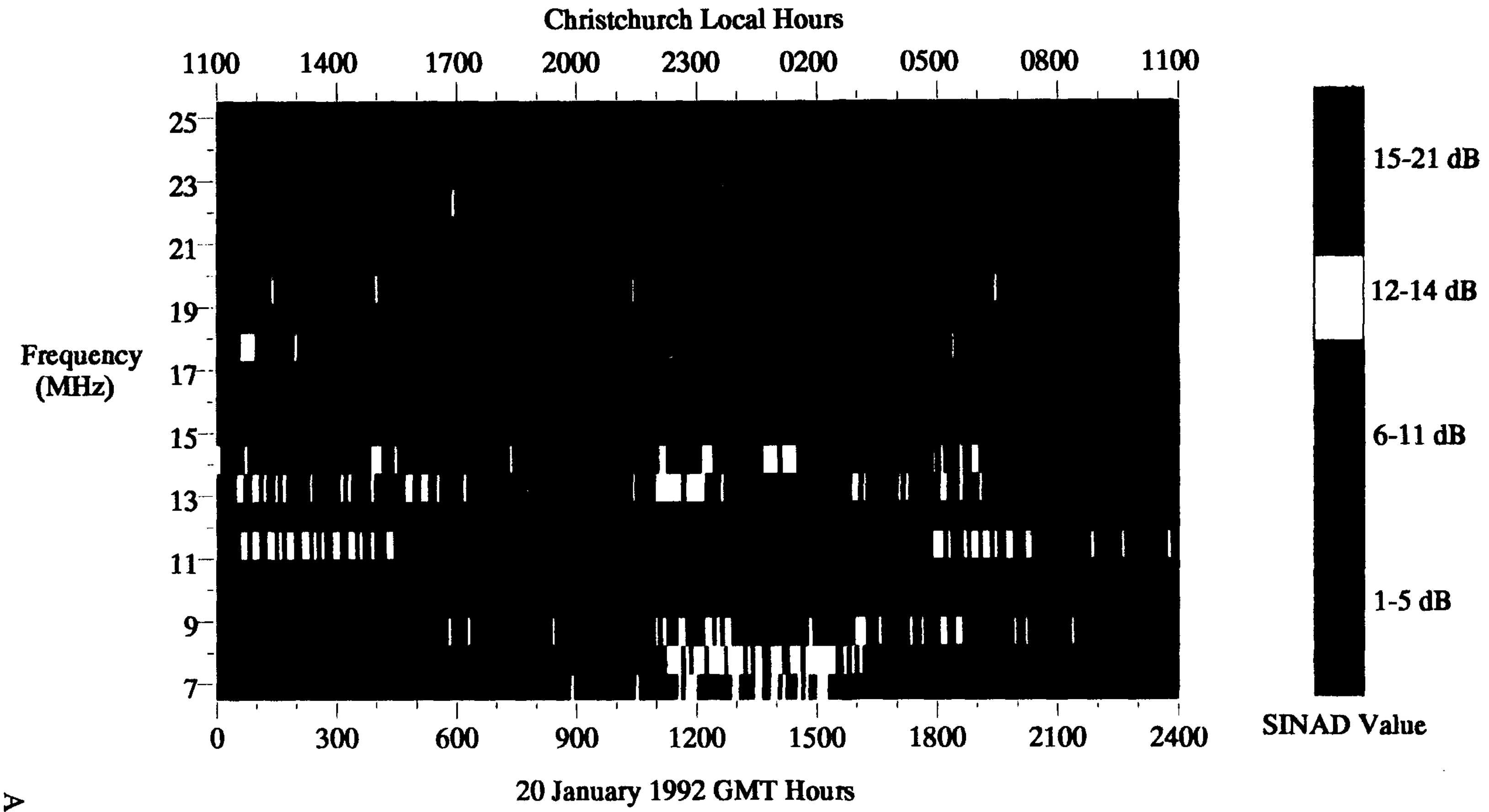

Figure A-30. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 20 January 1992

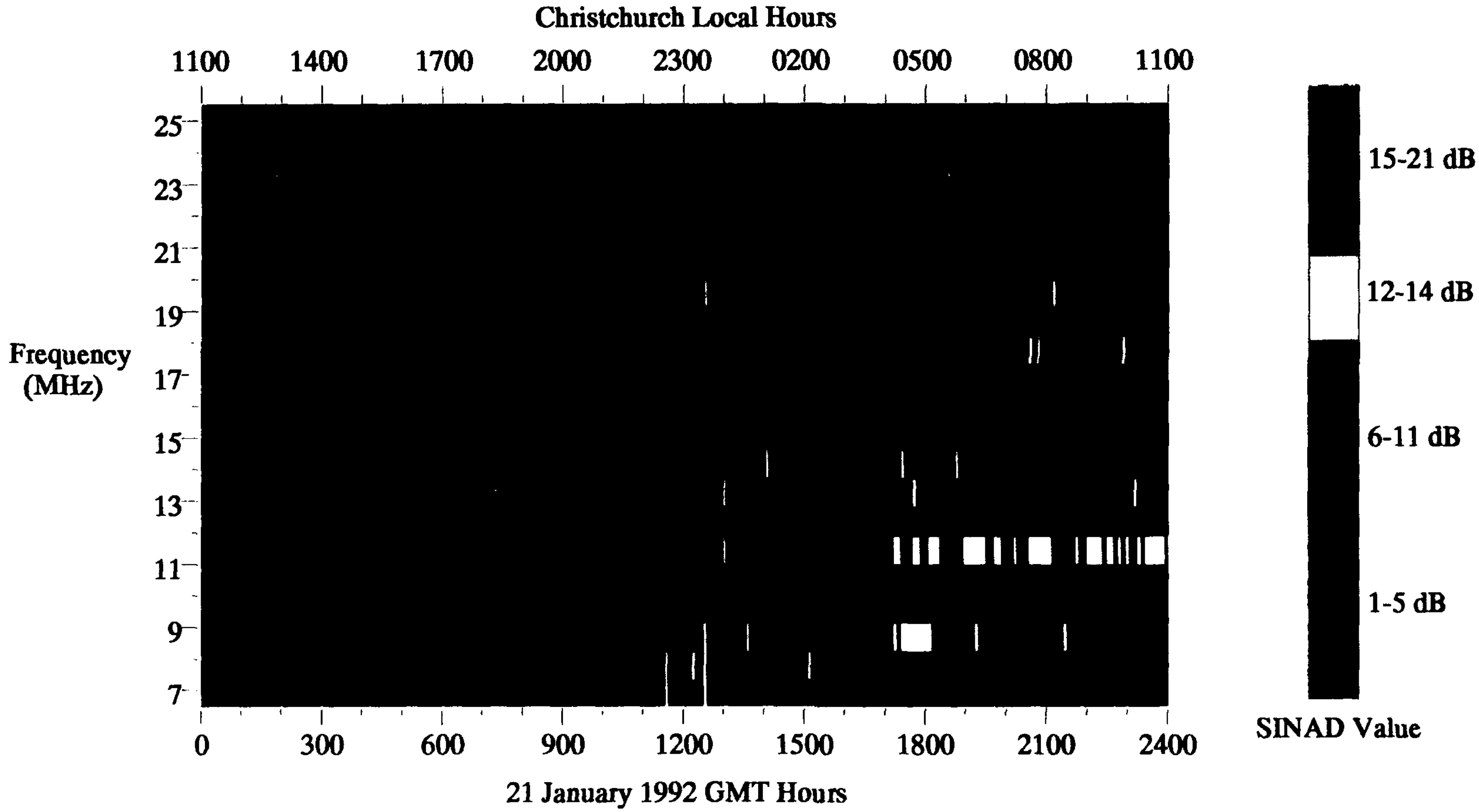

Figure A-31. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 21 January 1992

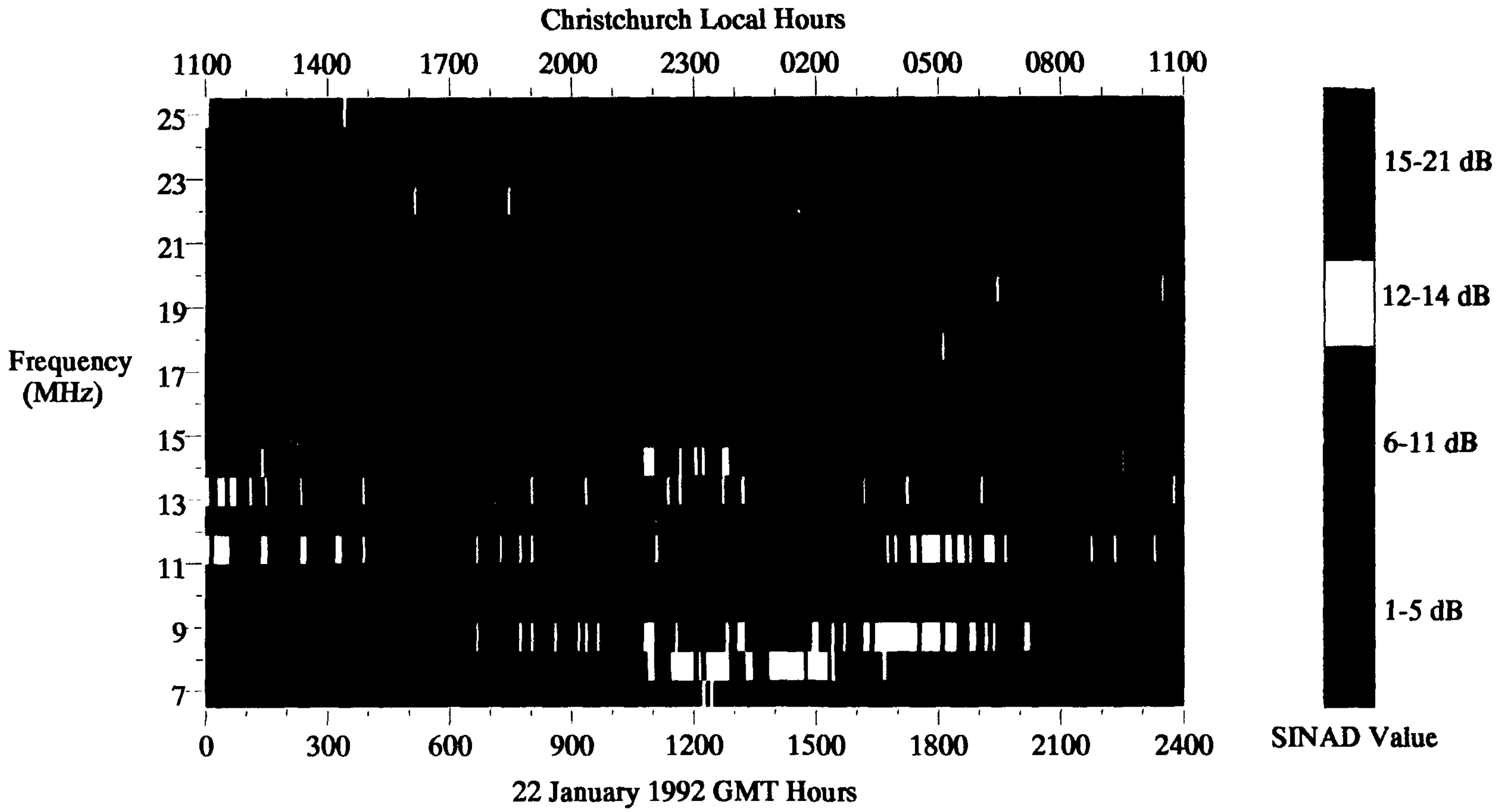

Figure A-32. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 22 January 1992

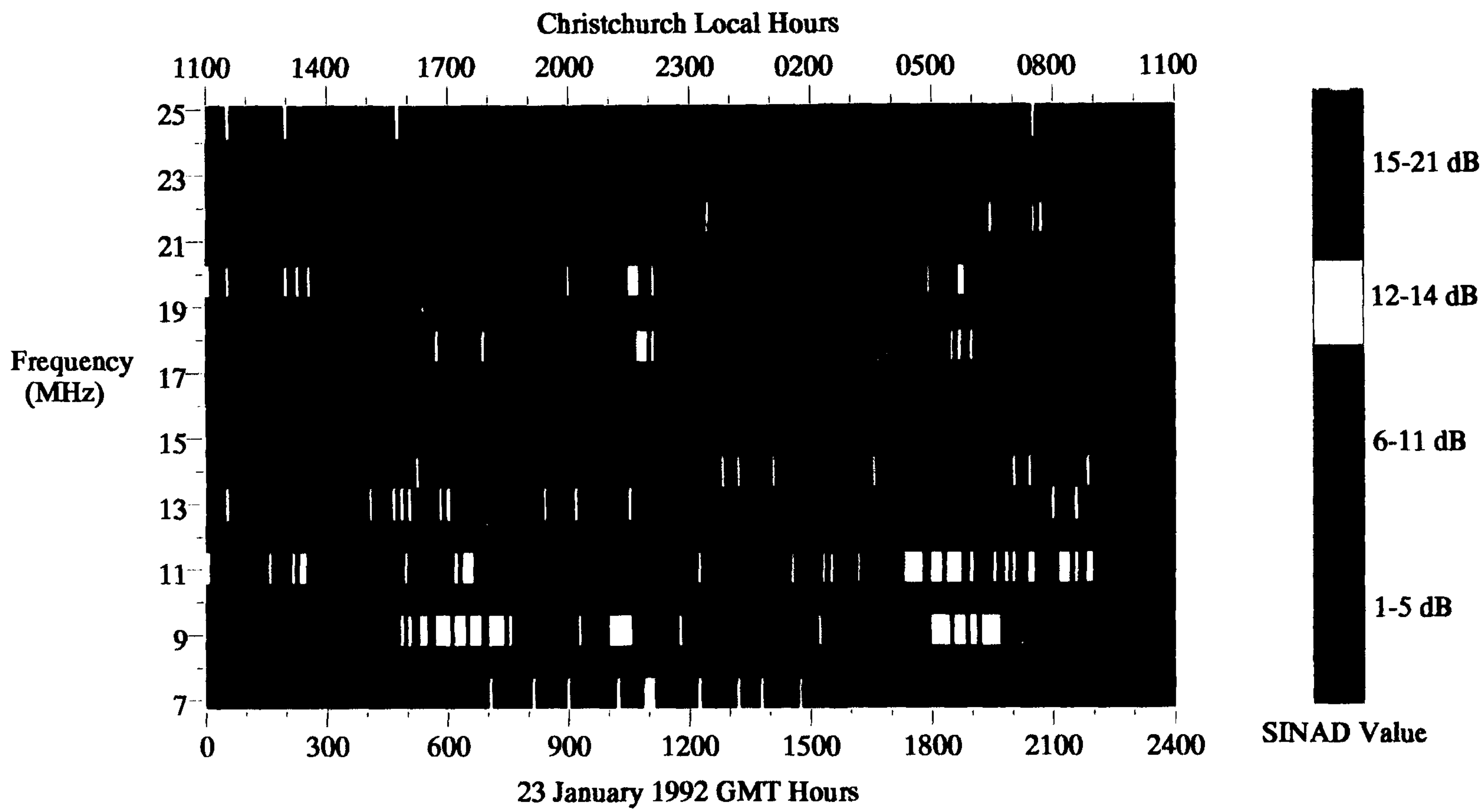

Figure A-33. SINAD Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 23 January 1992

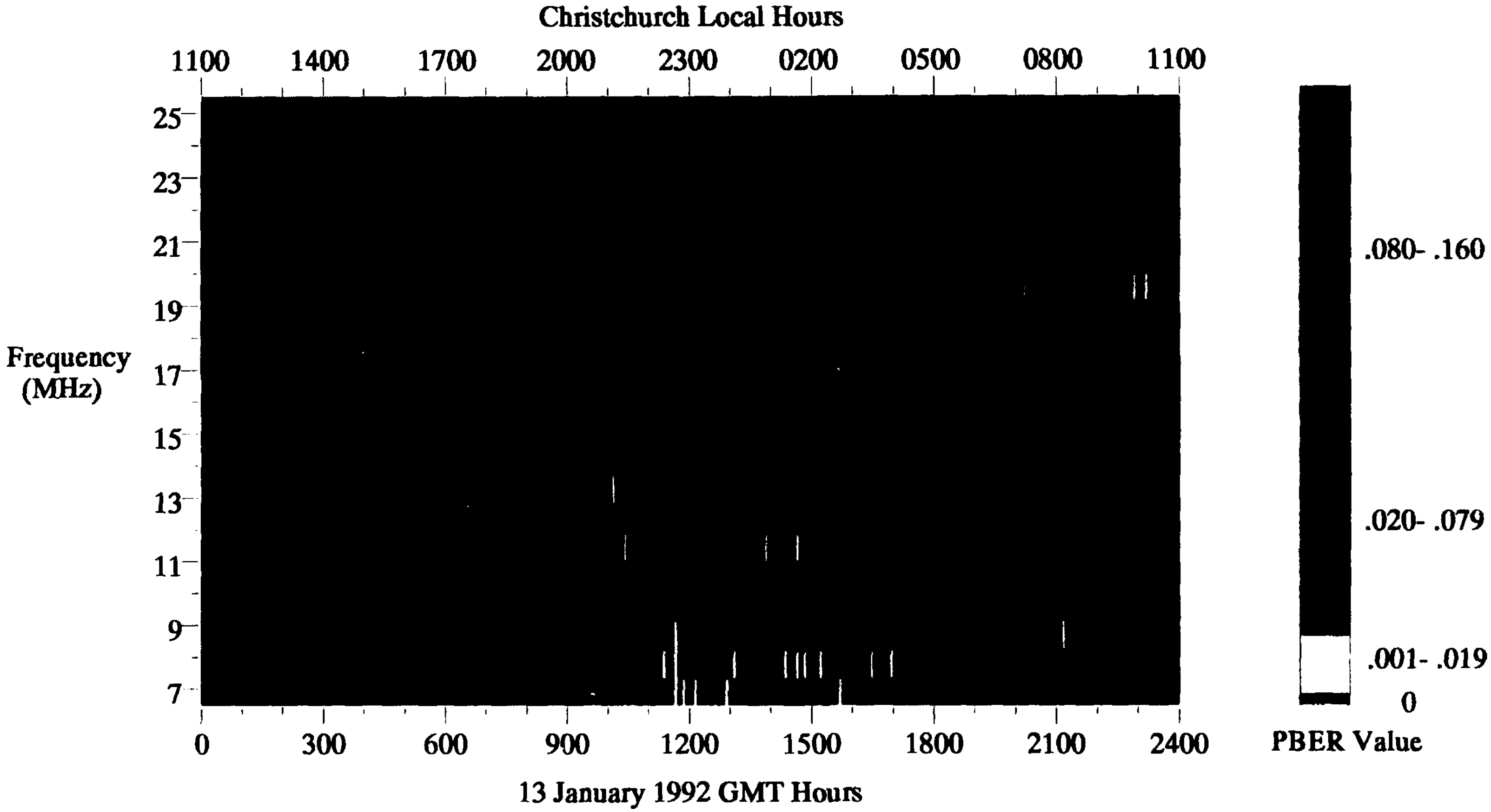

Figure A-34. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 13 January 1992

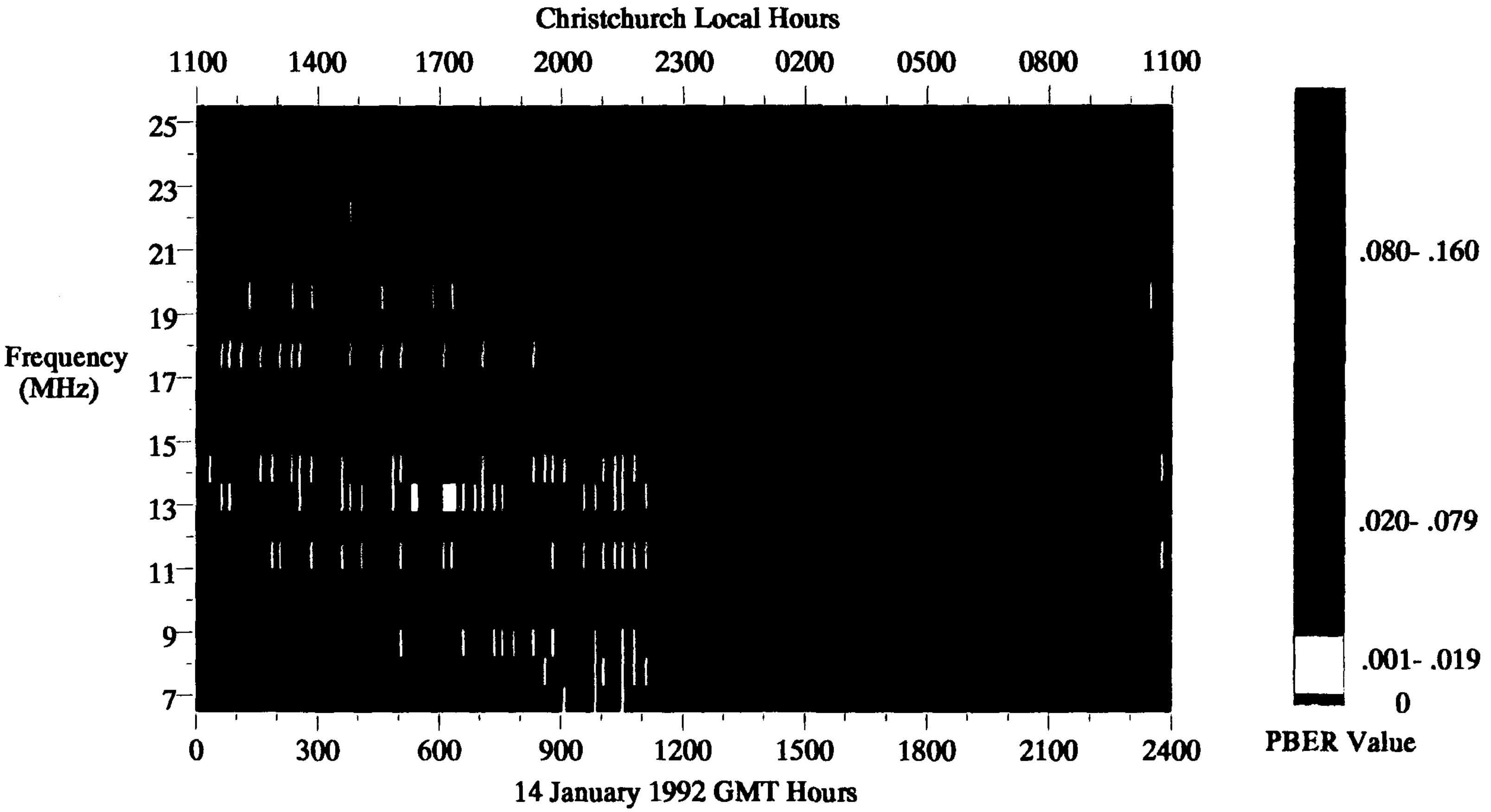

Figure A-35. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 14 January 1992

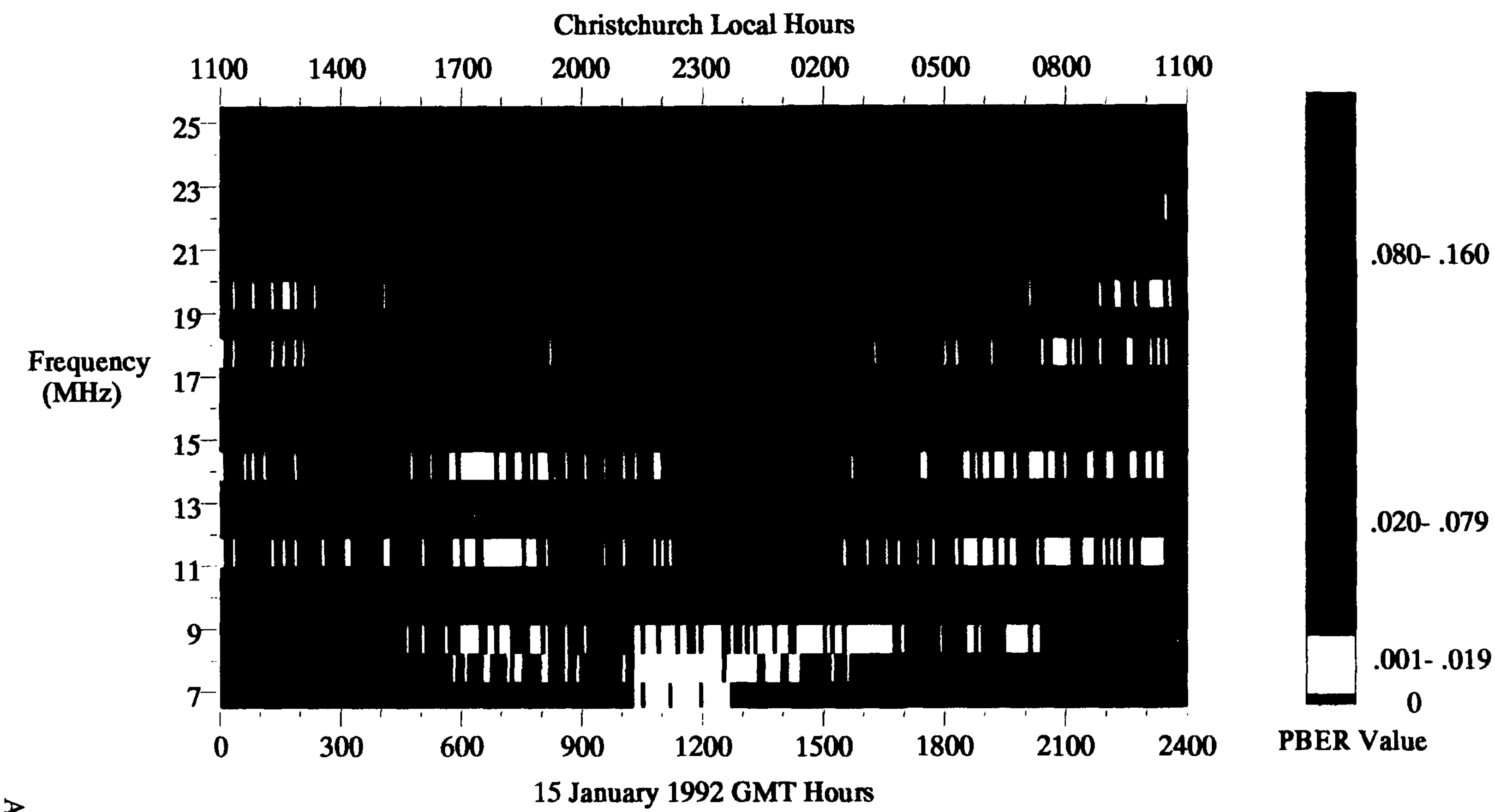

Figure A-36. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 15 January 1992

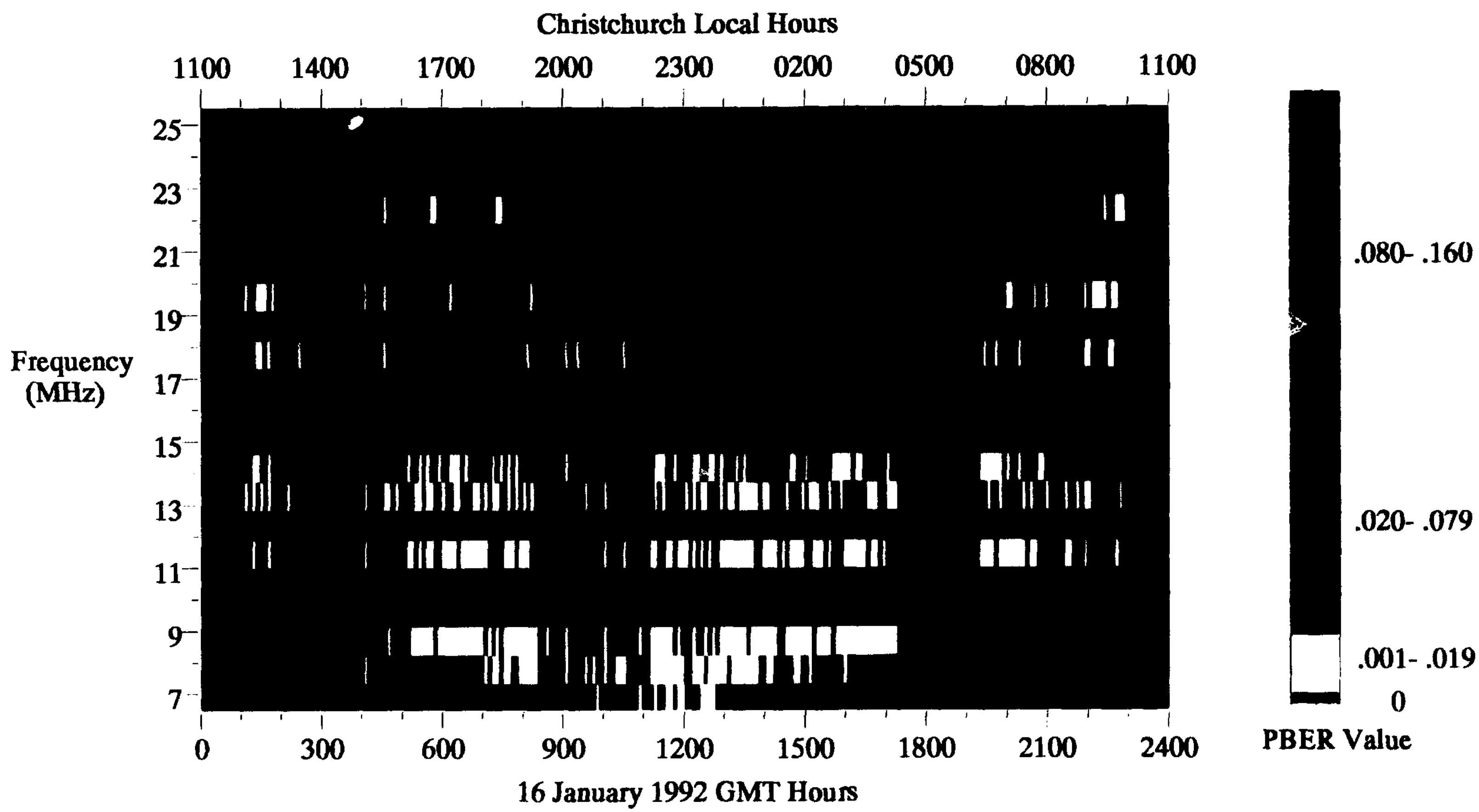

Figure A-37. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 16 January 1992

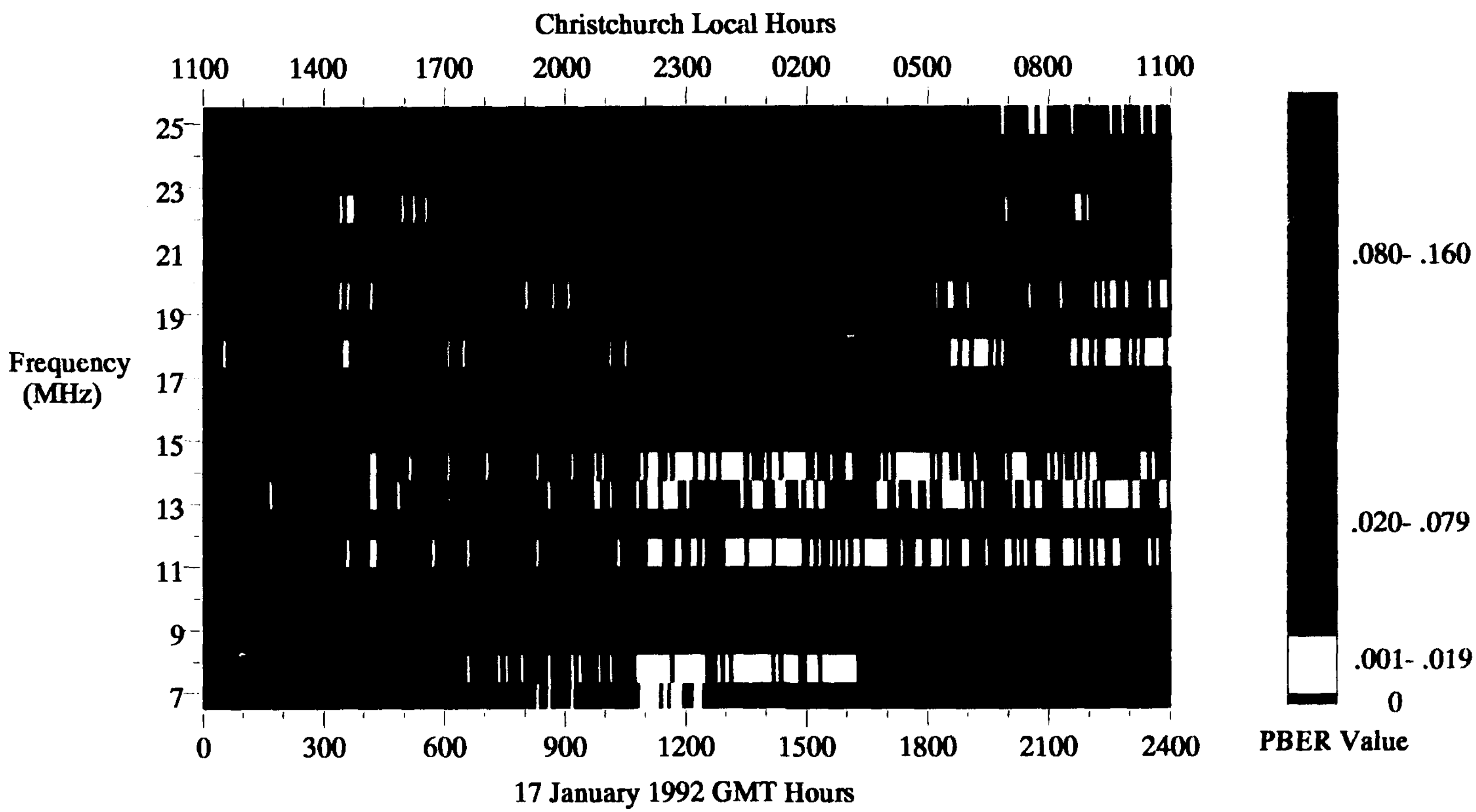

Figure A-38. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 17 January 1992

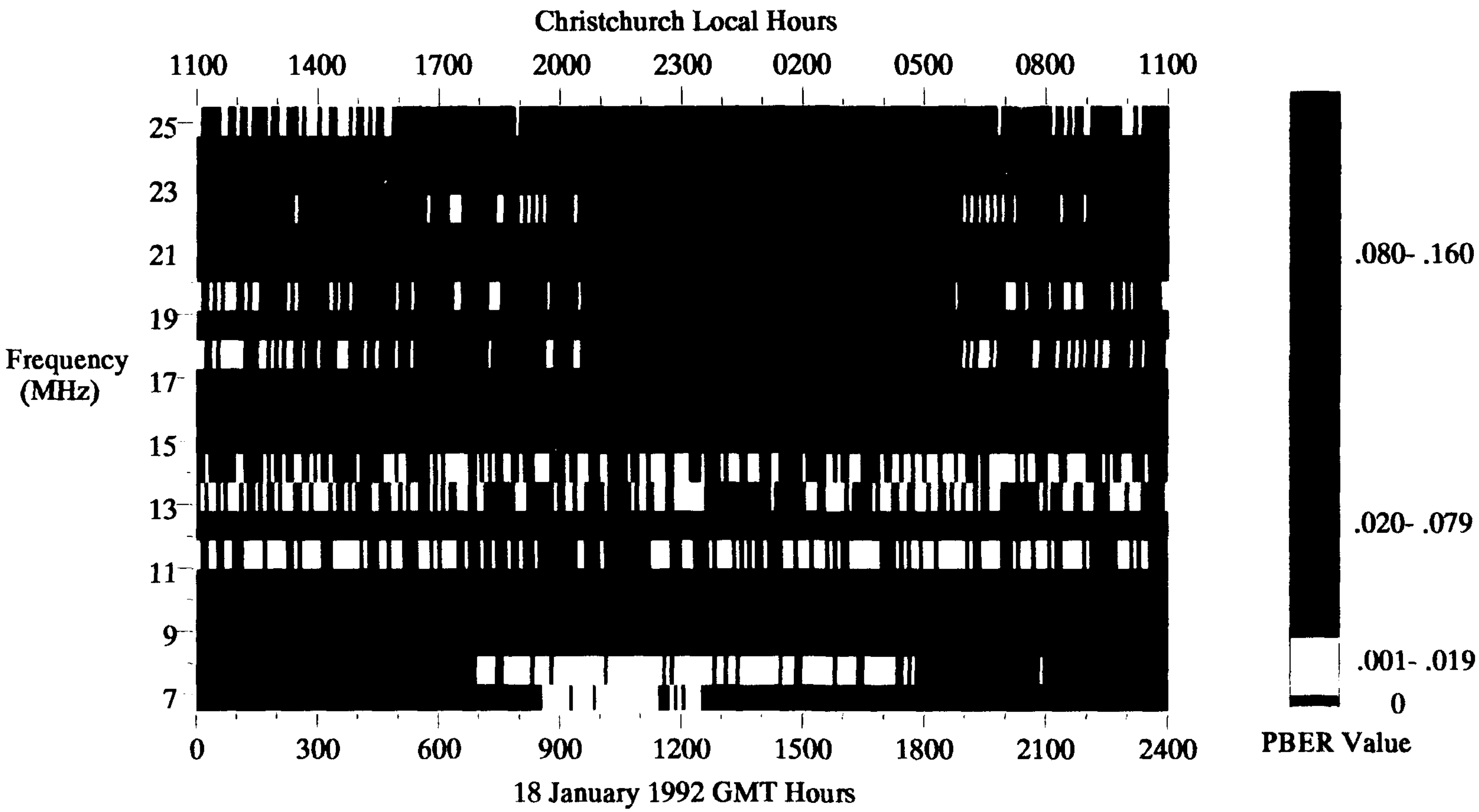

Figure A-39. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 18 January 1992

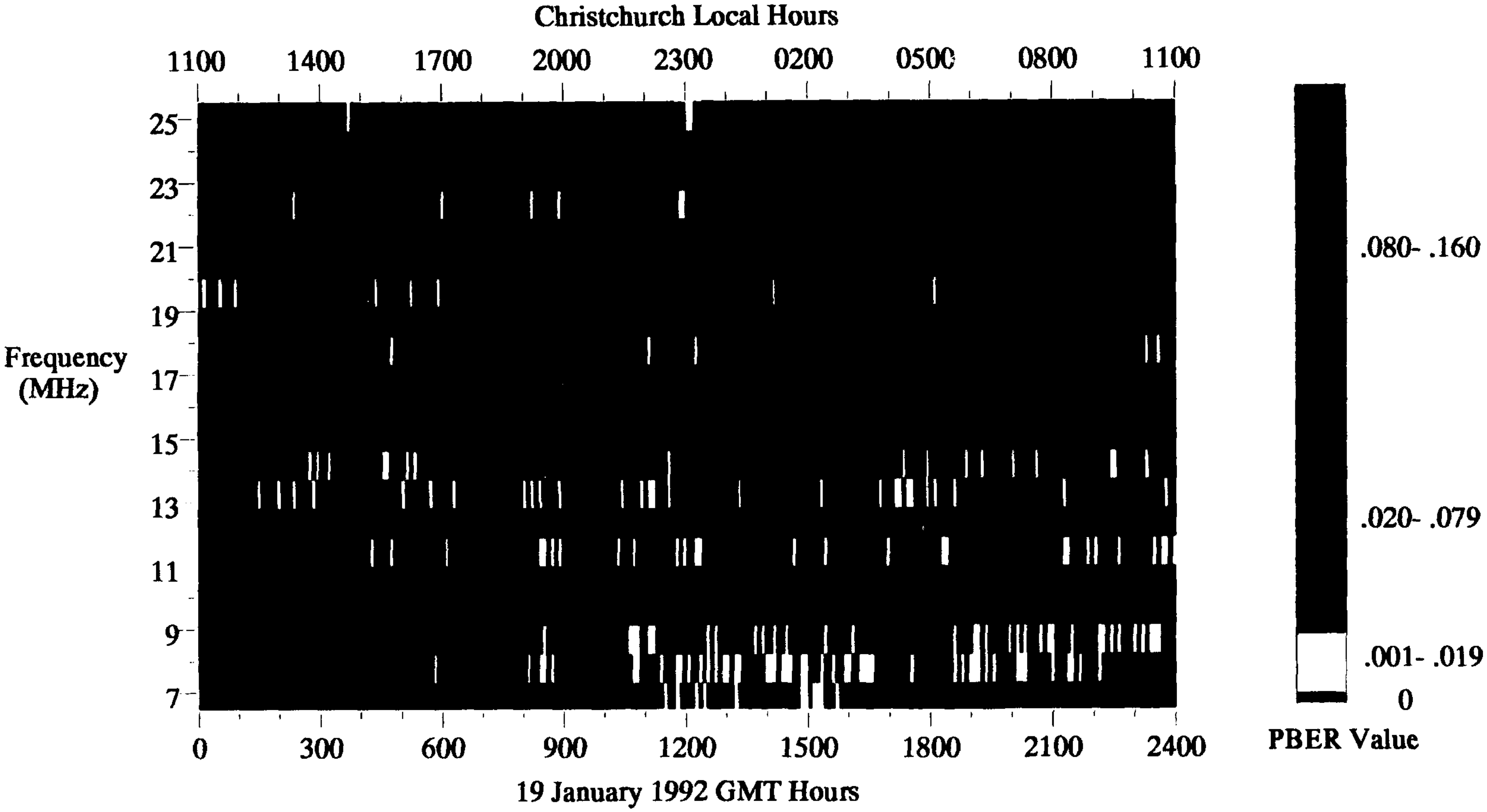

Figure A-40. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 19 January 1992

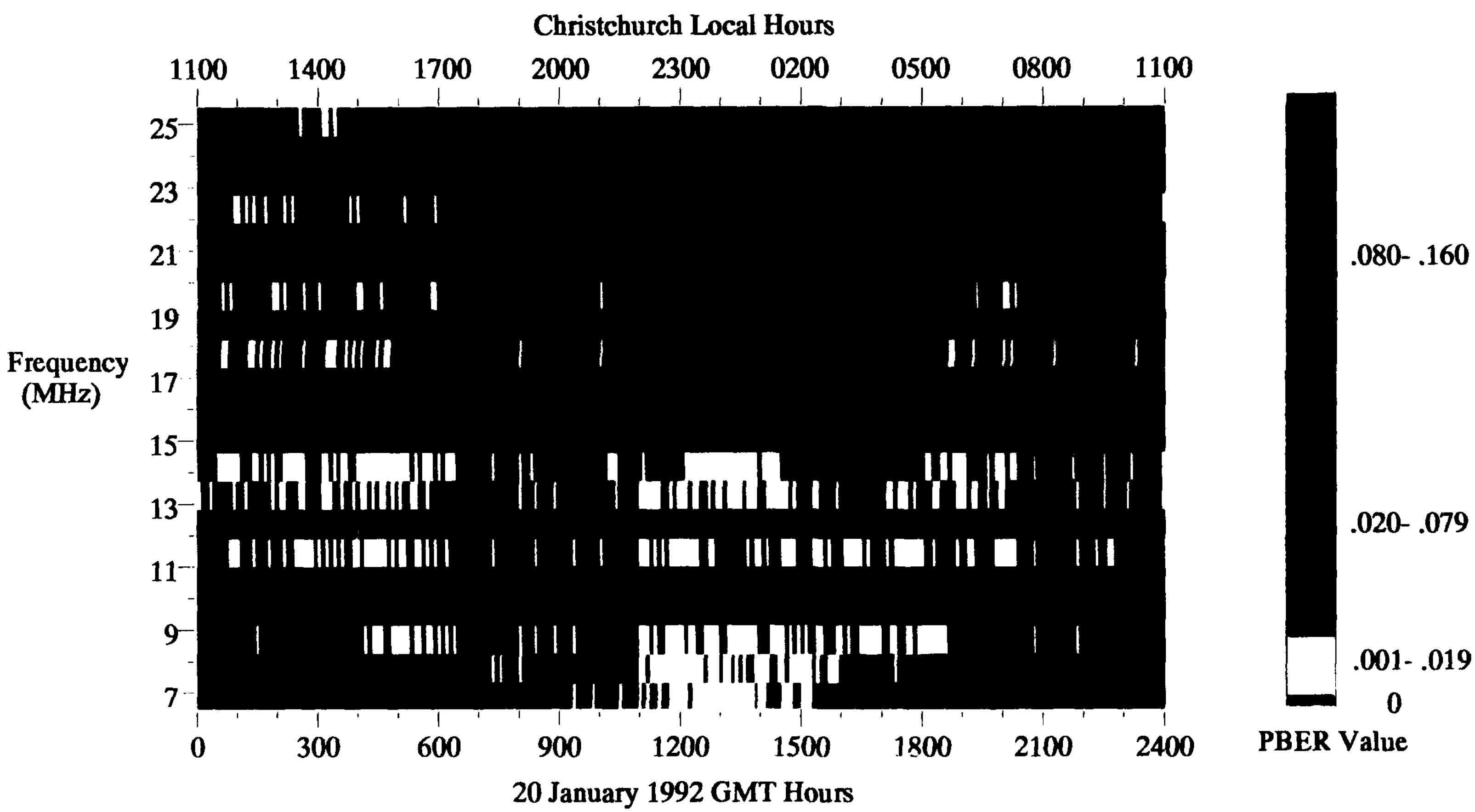

Figure A-41. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 20 January 1992

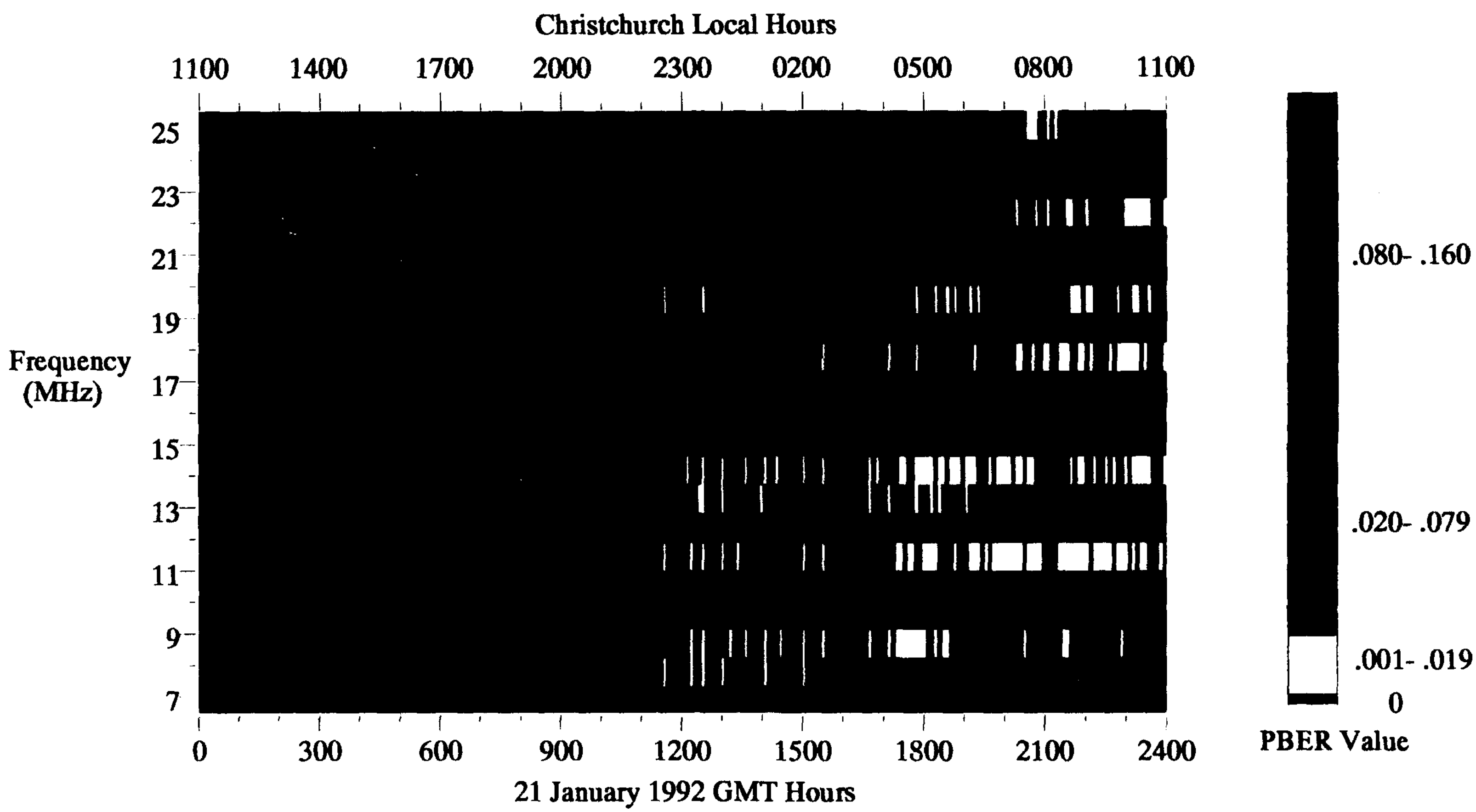

Figure A-42. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 21 January 1992

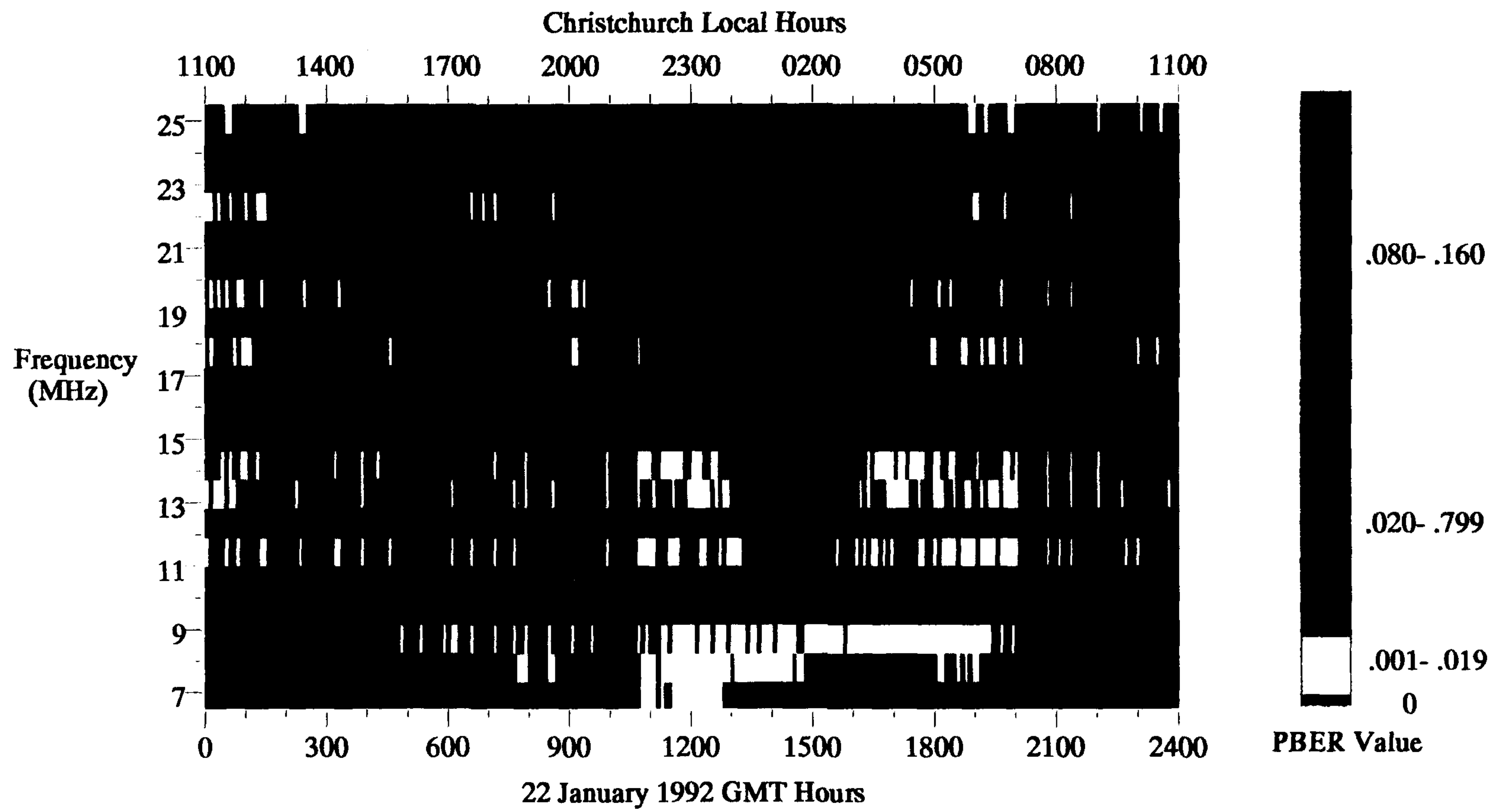

Figure A-43. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 22 January 1992

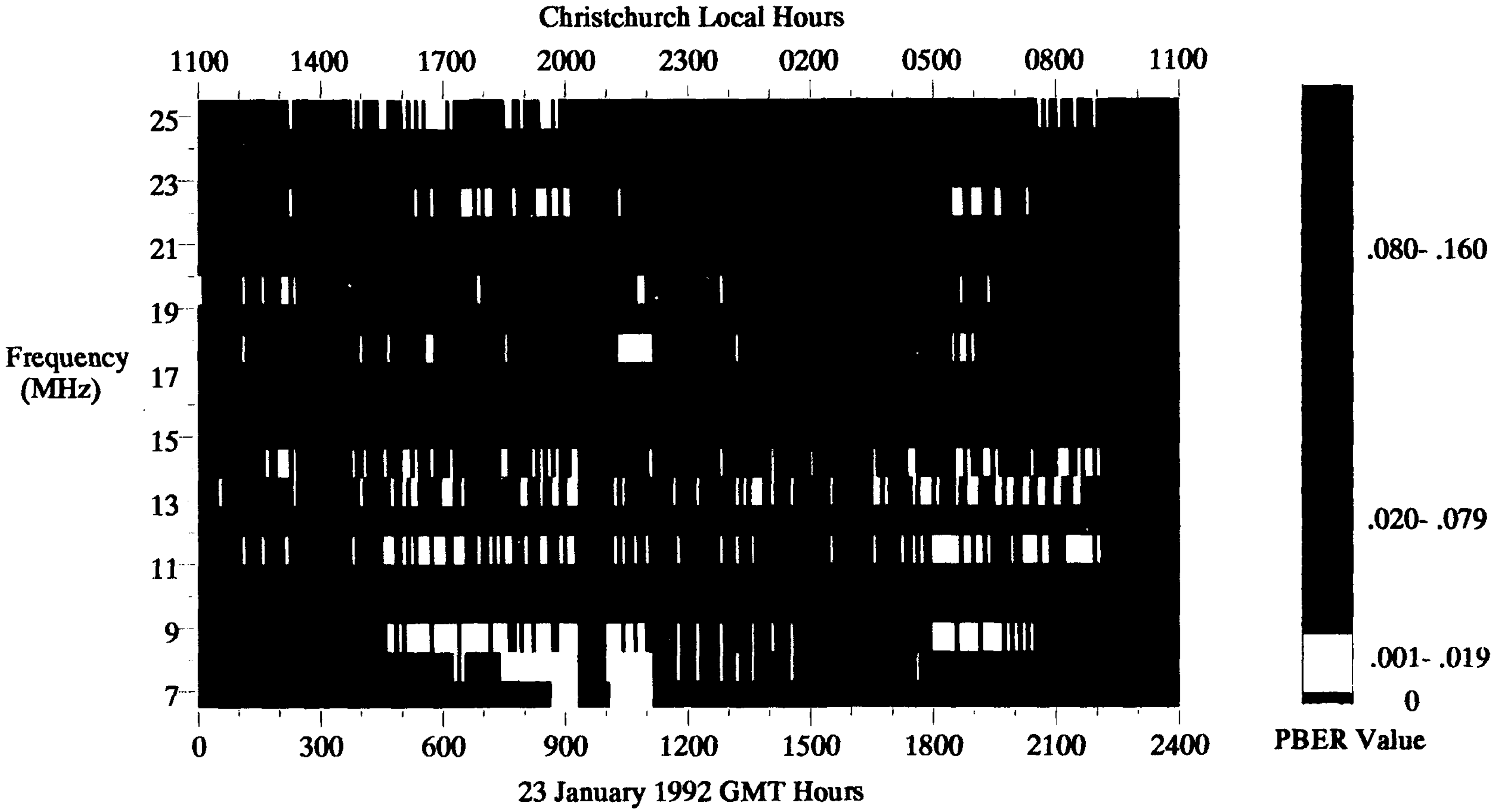

Figure A-44. PBER Measured at Black Island, Antarctica, for Link to Christchurch, NZ, 23 January 1992

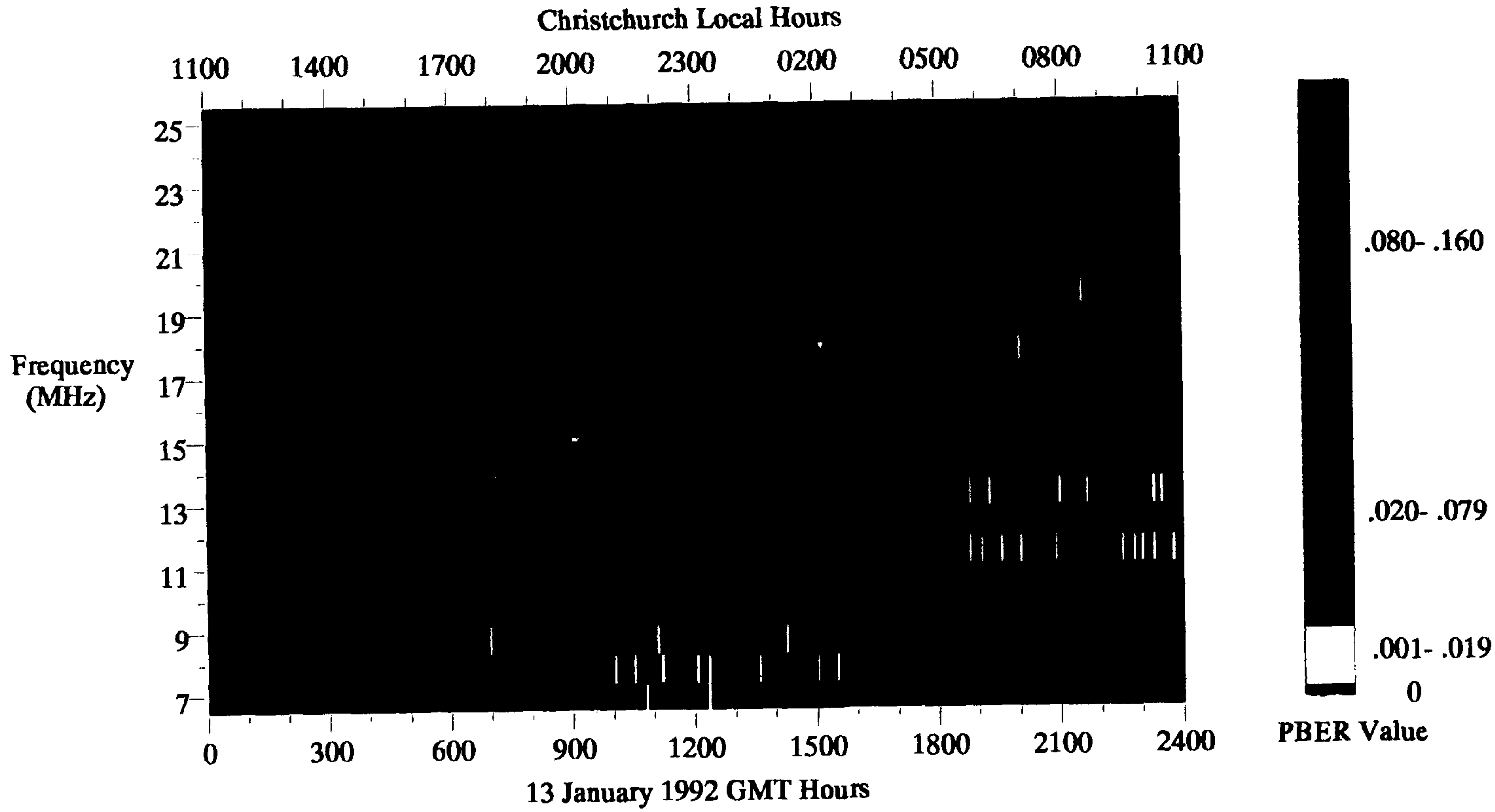

Figure A-45. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 13 January 1992

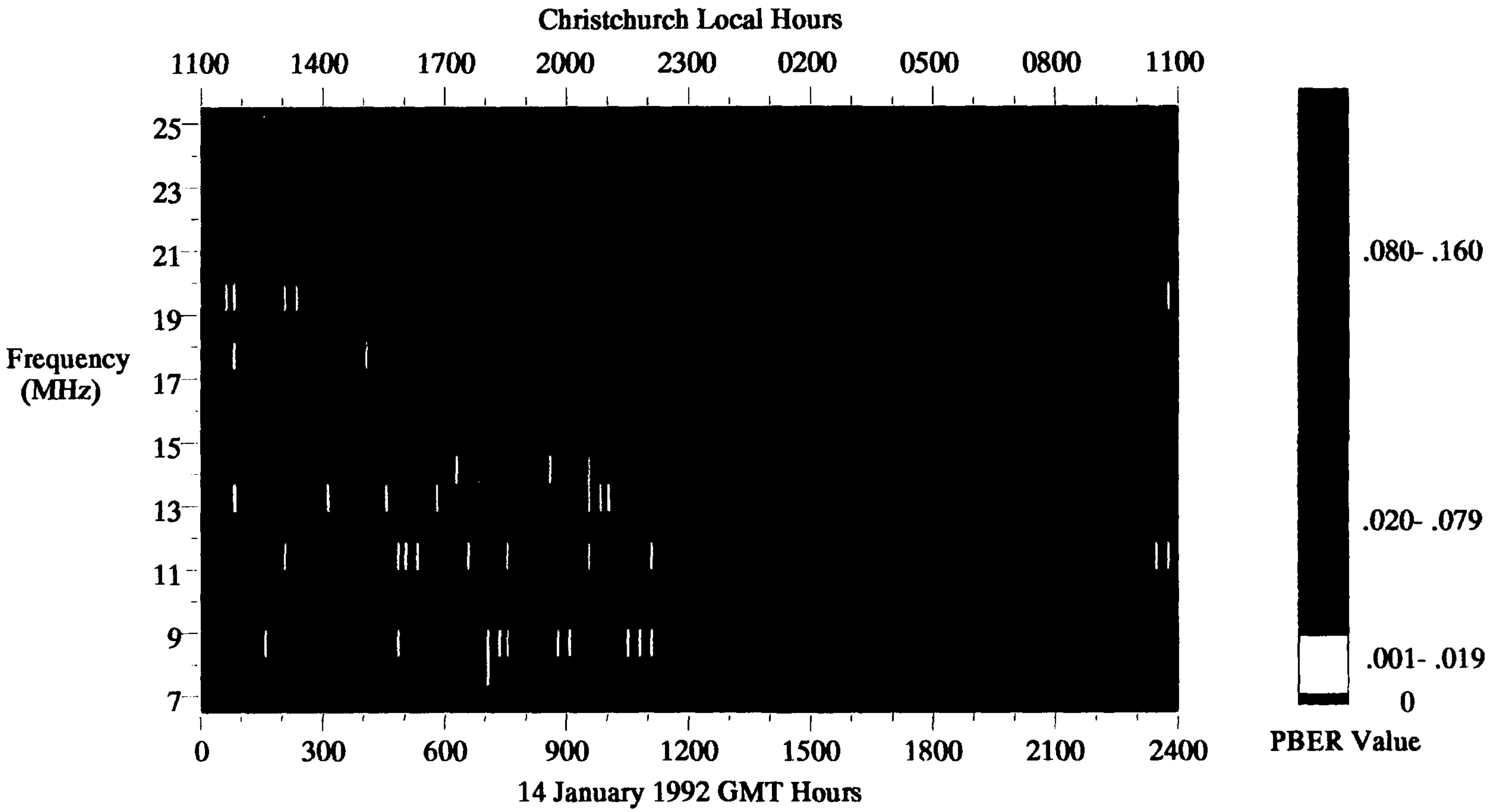

Figure A-46. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 14 January 1992

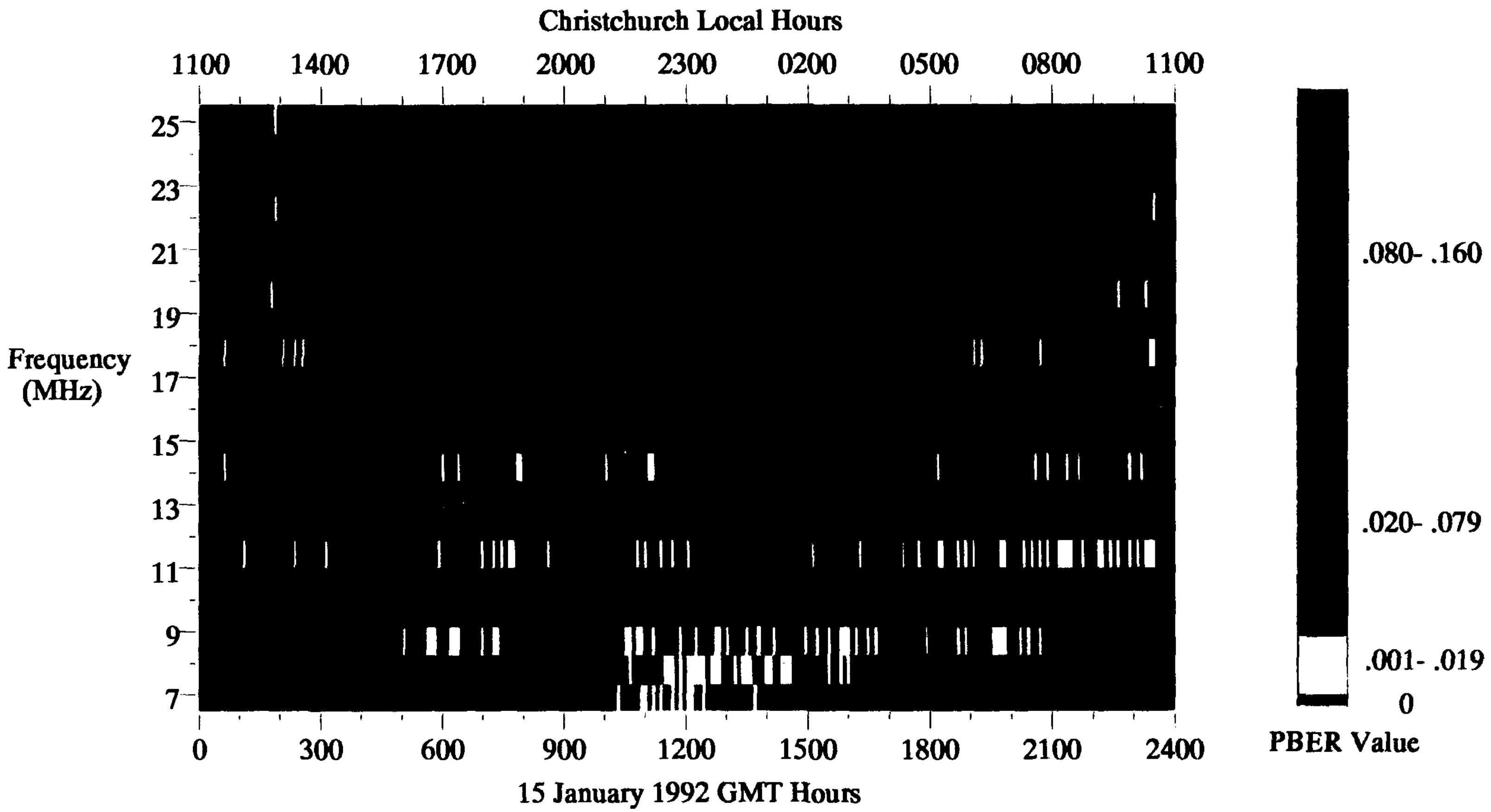

Figure A-47. *PBER Measured at Christchurch, NZ, for Link* to Black Island, Antarctica, 15 January 1992

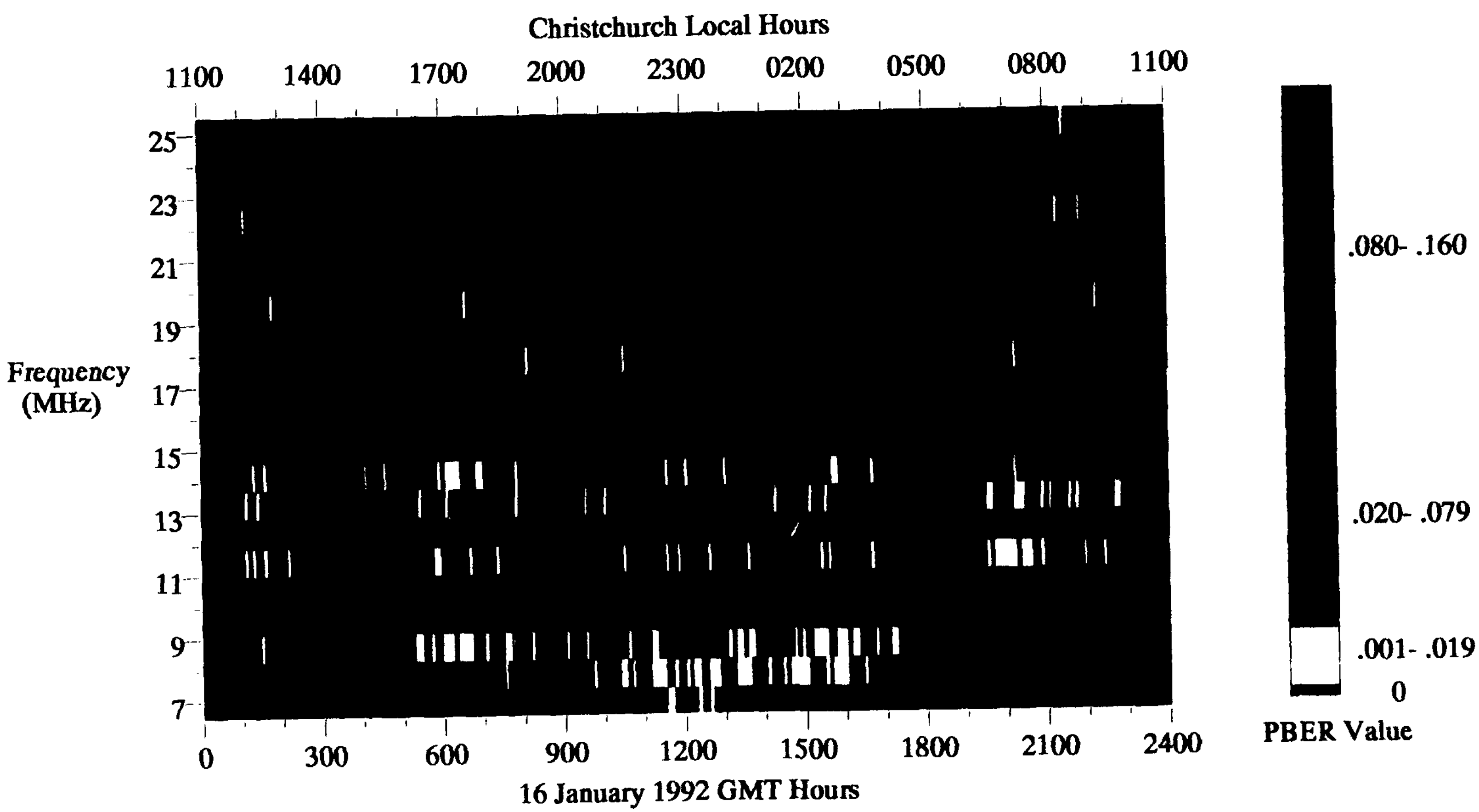

Figure A-48. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 16 January 1992

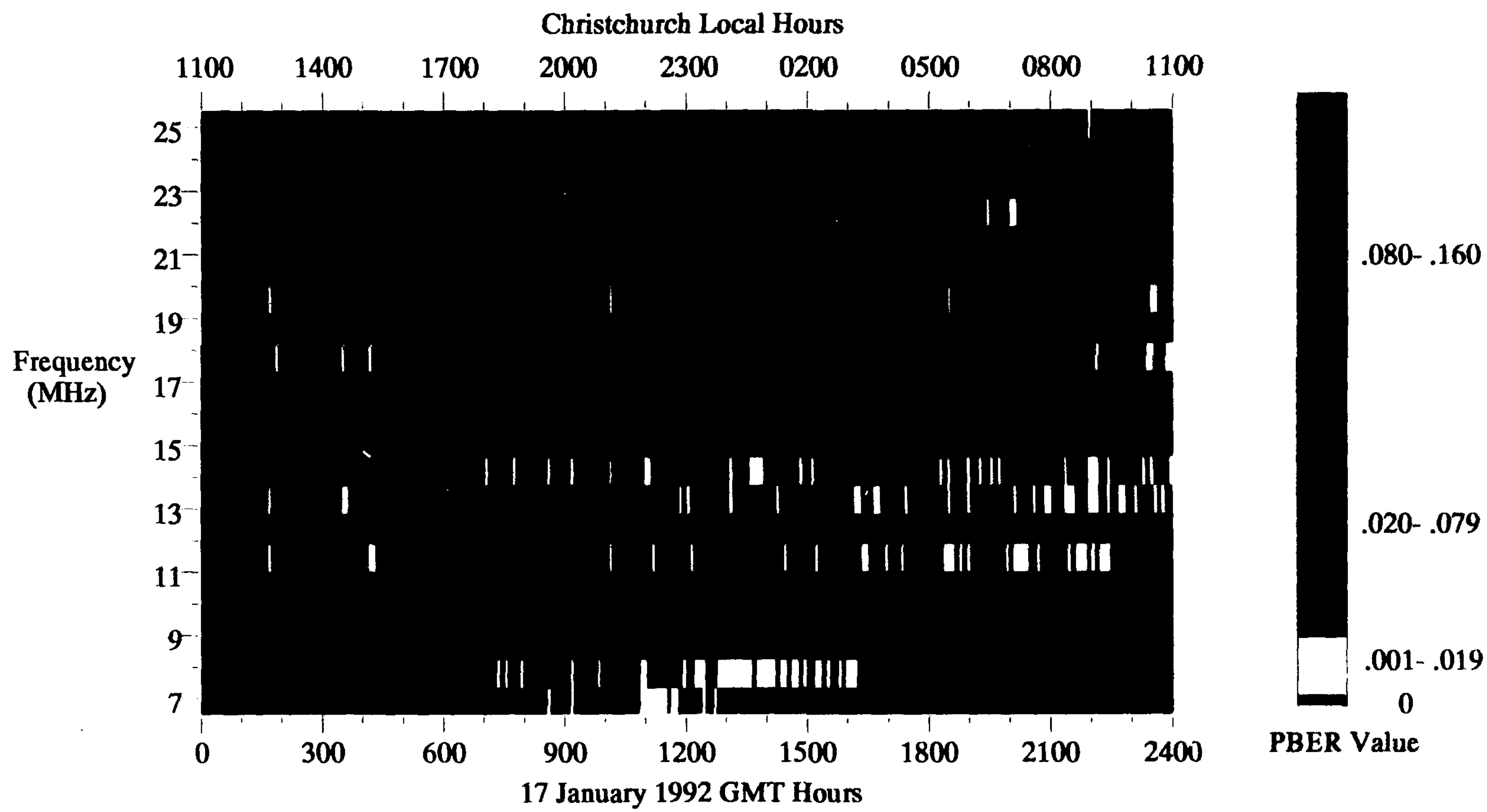

Figure A-49. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 17 January 1992

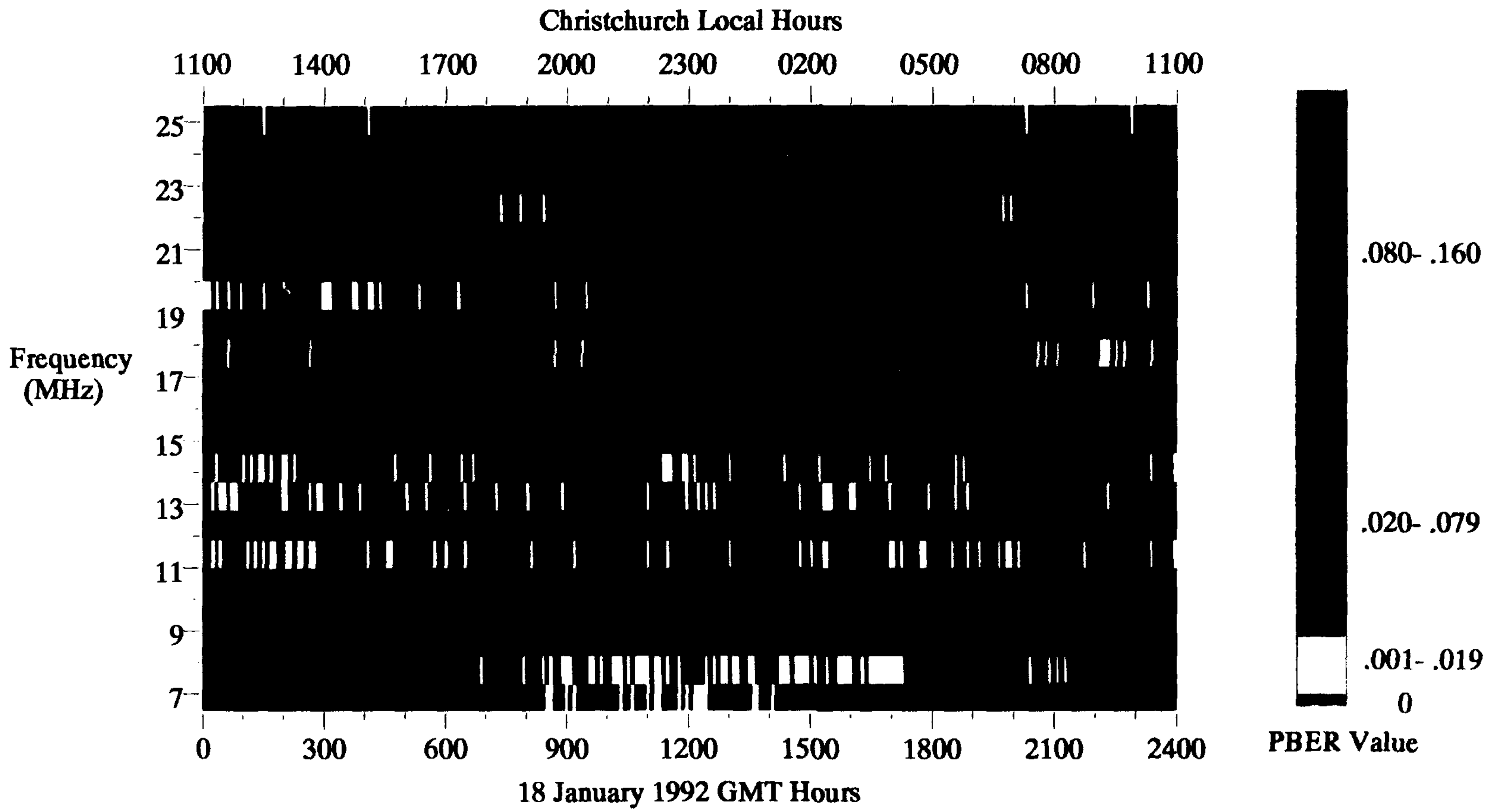

Figure A-50. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 18 January 1992

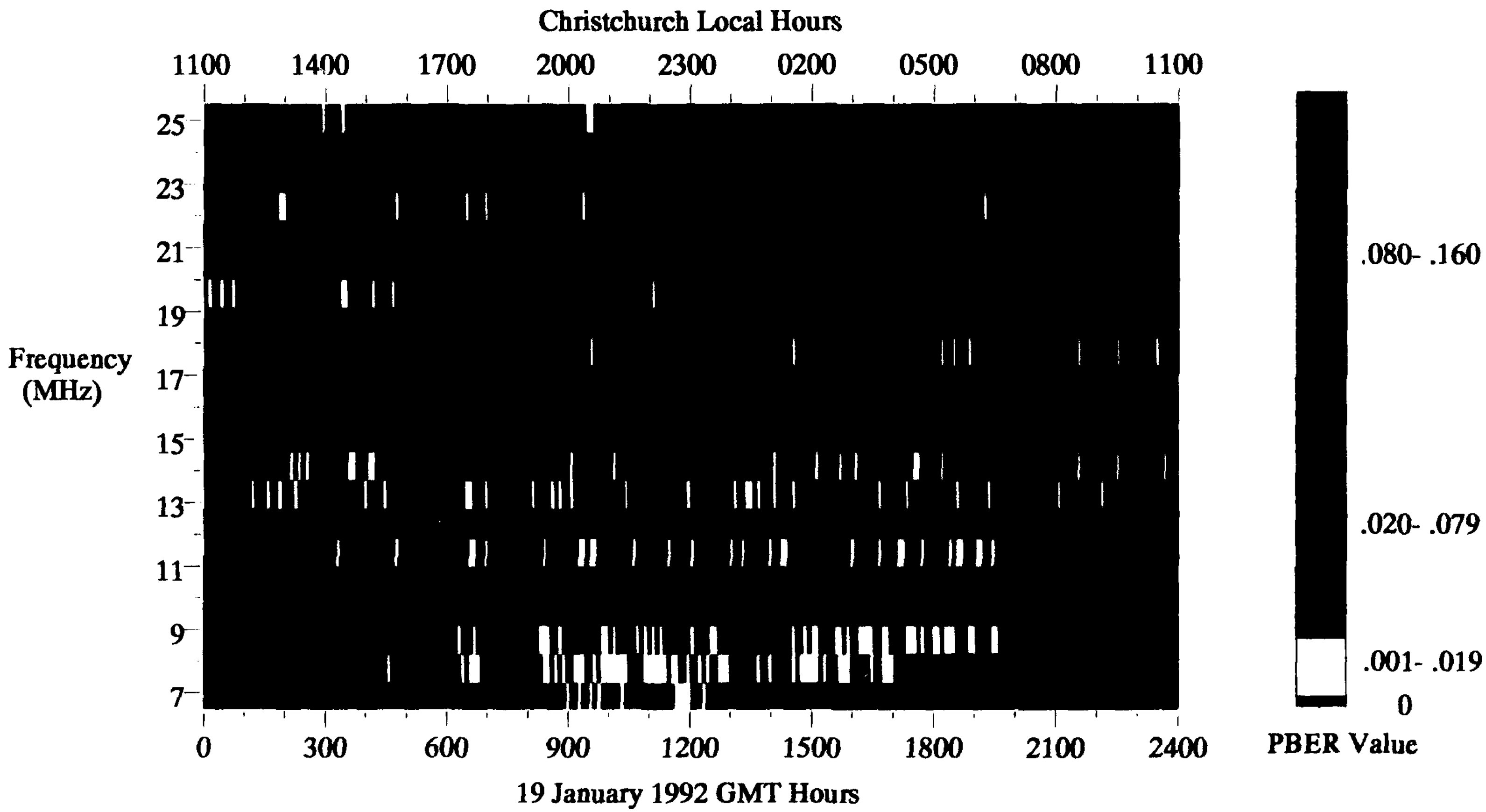

Figure A-51. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 19 January 1992

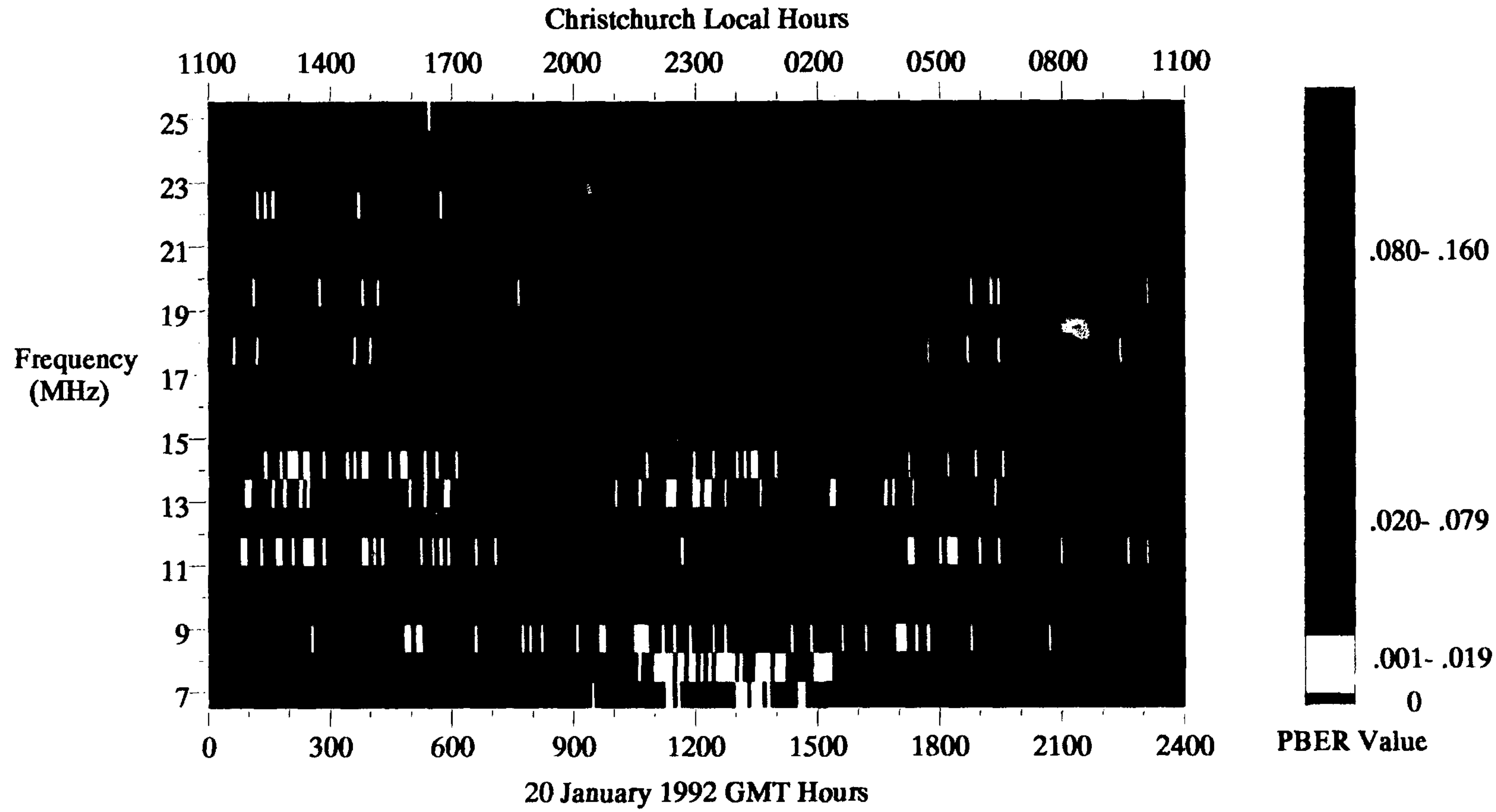

Figure A-52. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 20 January 1992

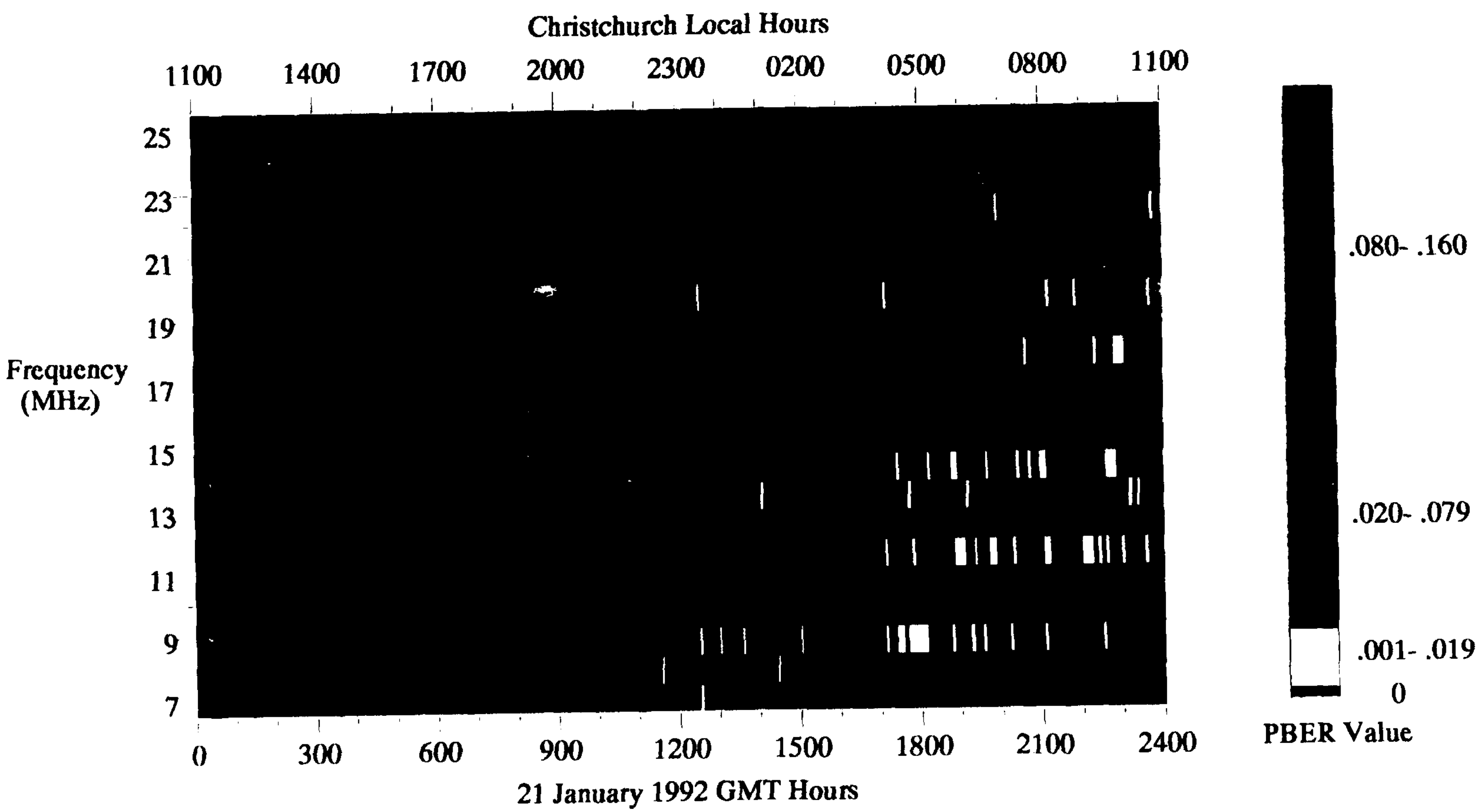

Figure A-53. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 21 January 1992

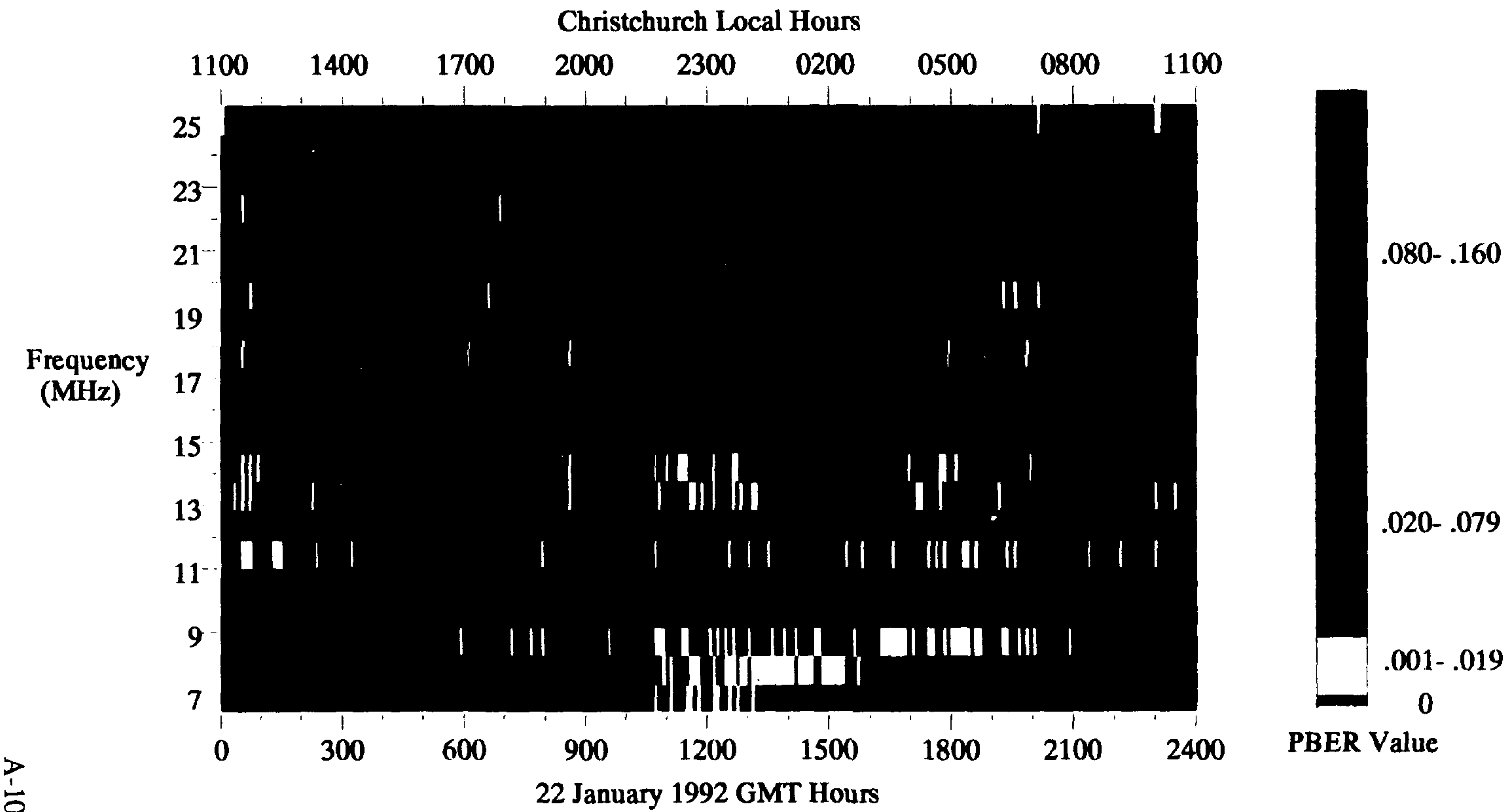

Figure A-54. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 22 January 1992

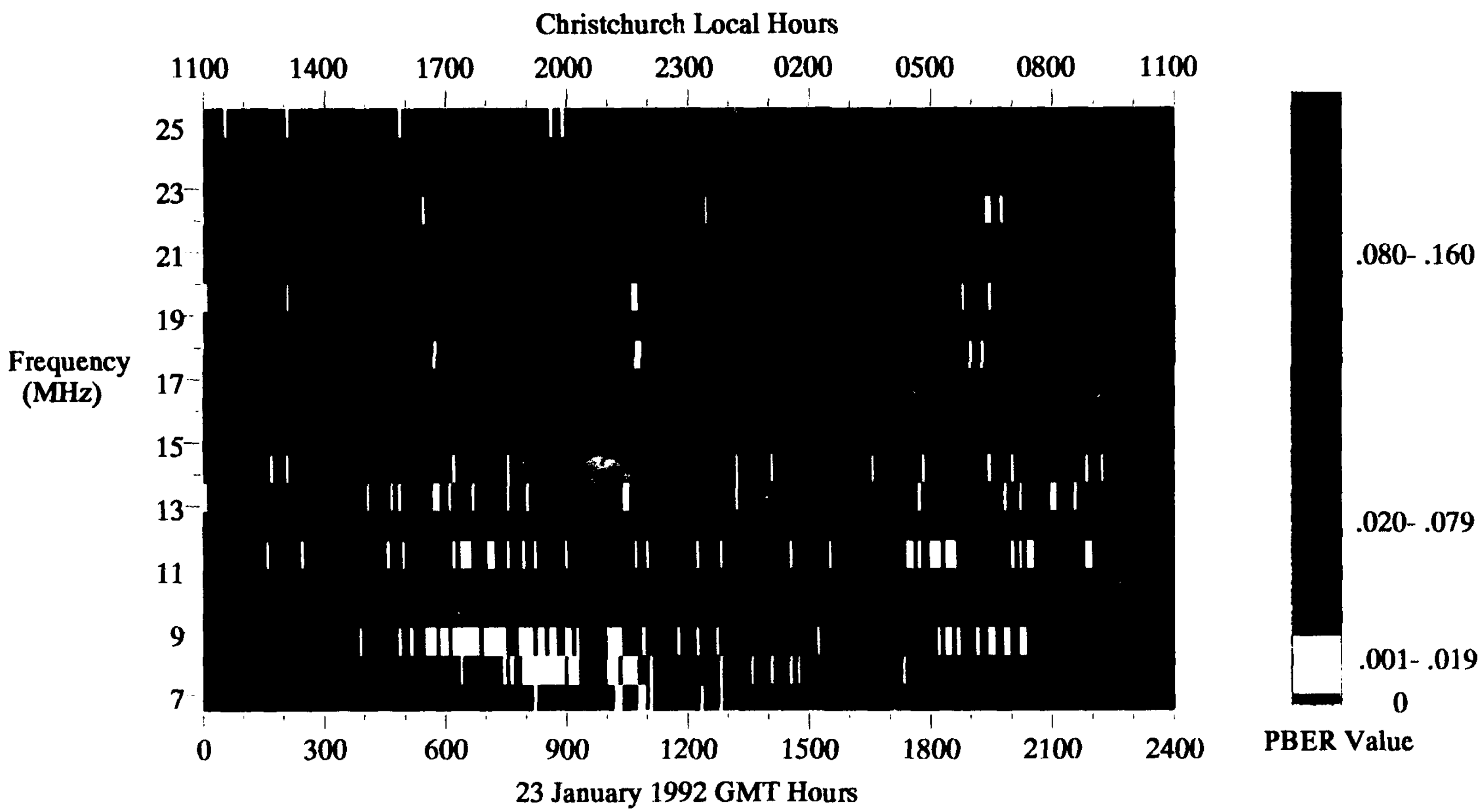

Figure A-55. PBER Measured at Christchurch, NZ, for Link to Black Island, Antarctica, 23 January 1992

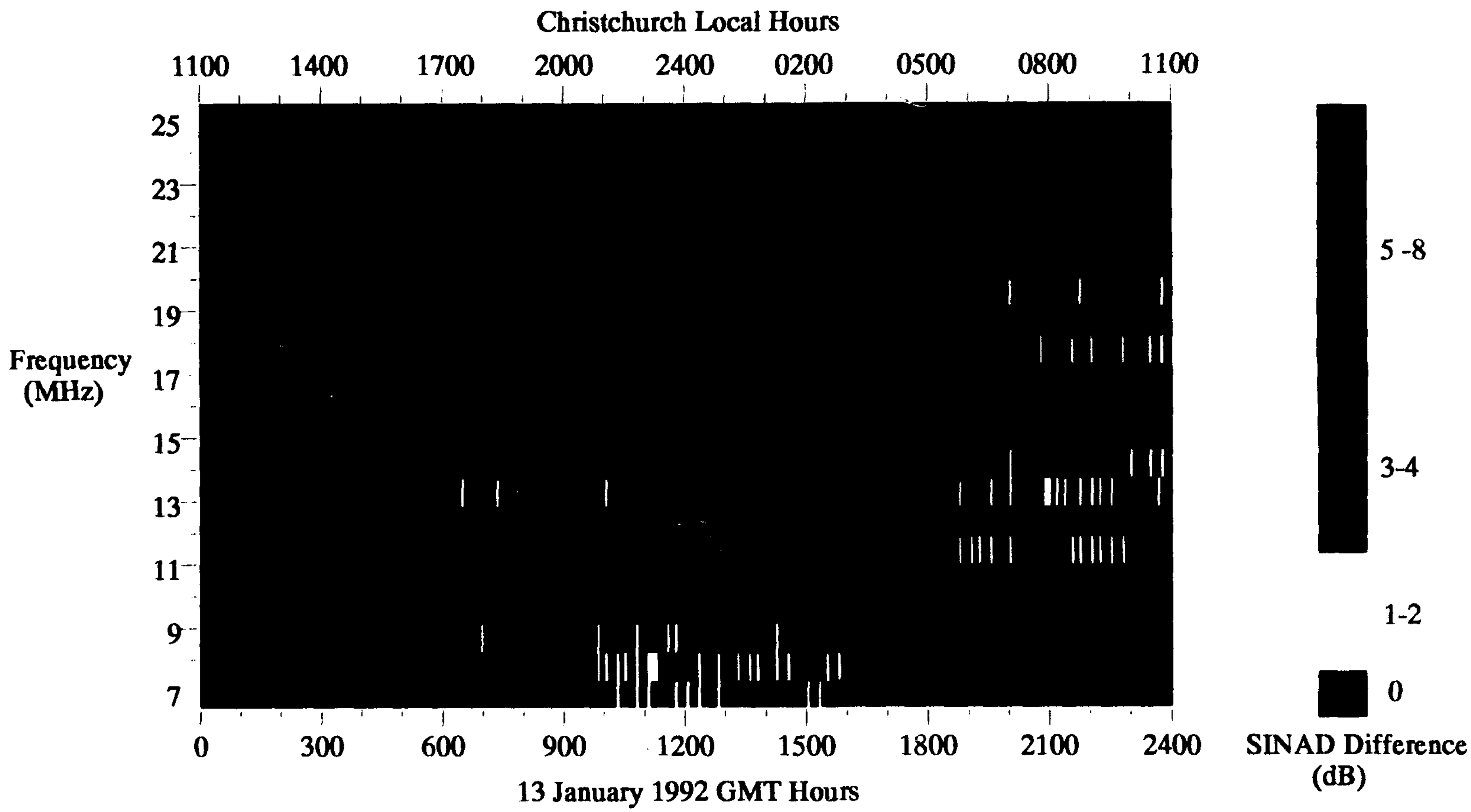

Figure A-56. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 13 January 1992

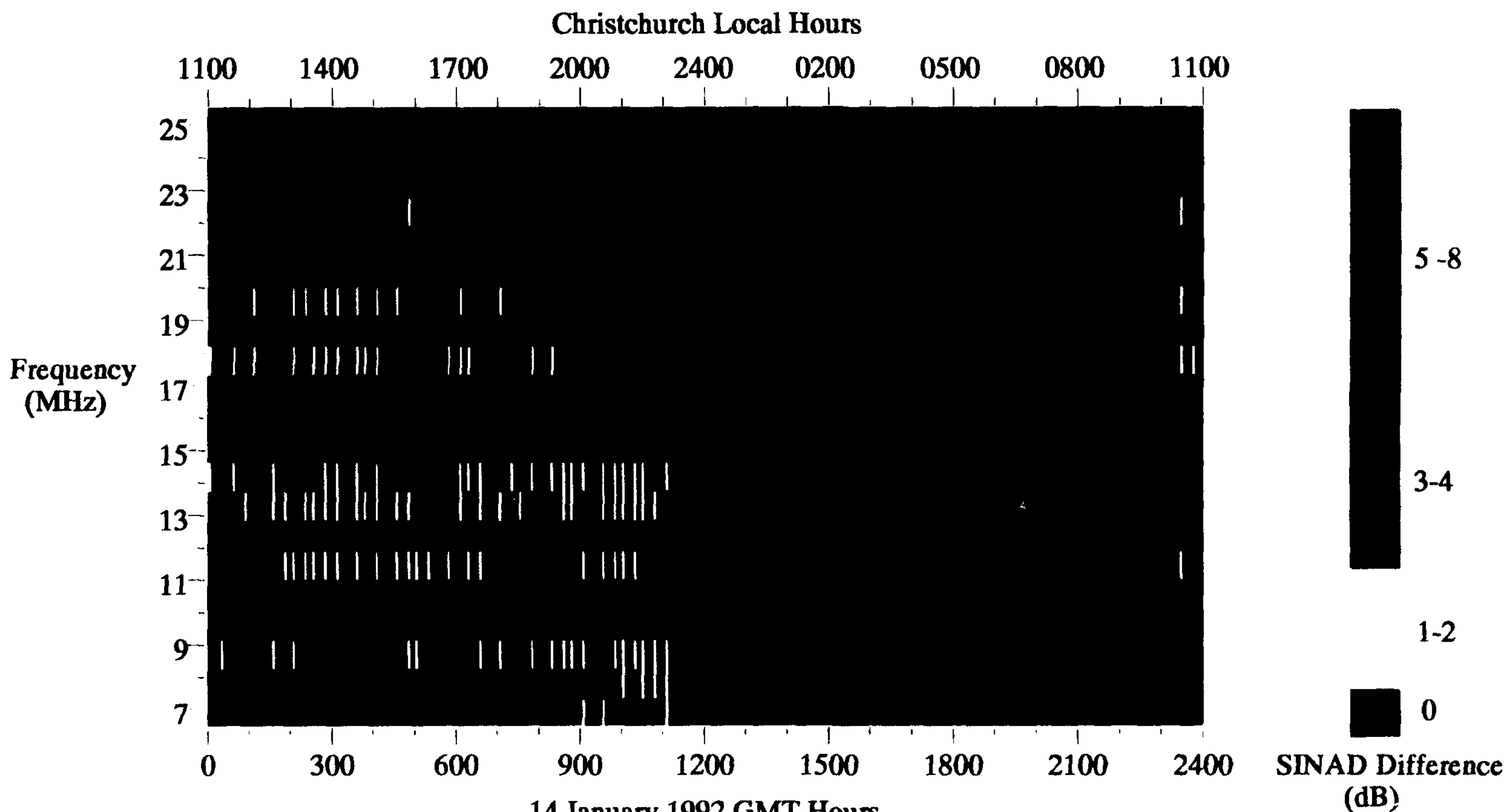

Figure A-57. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 14 January 1992

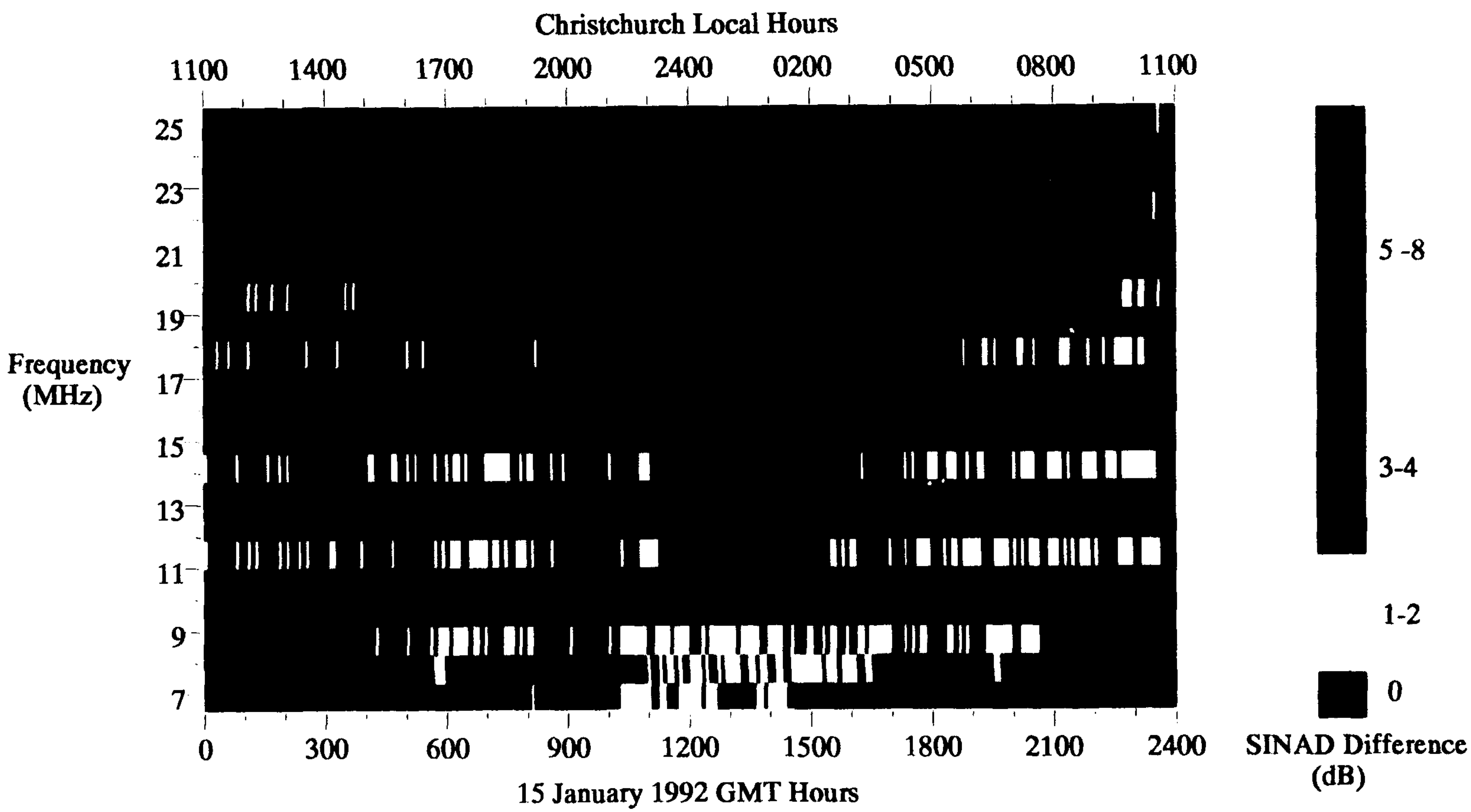

Figure A-58. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 15 January 1992

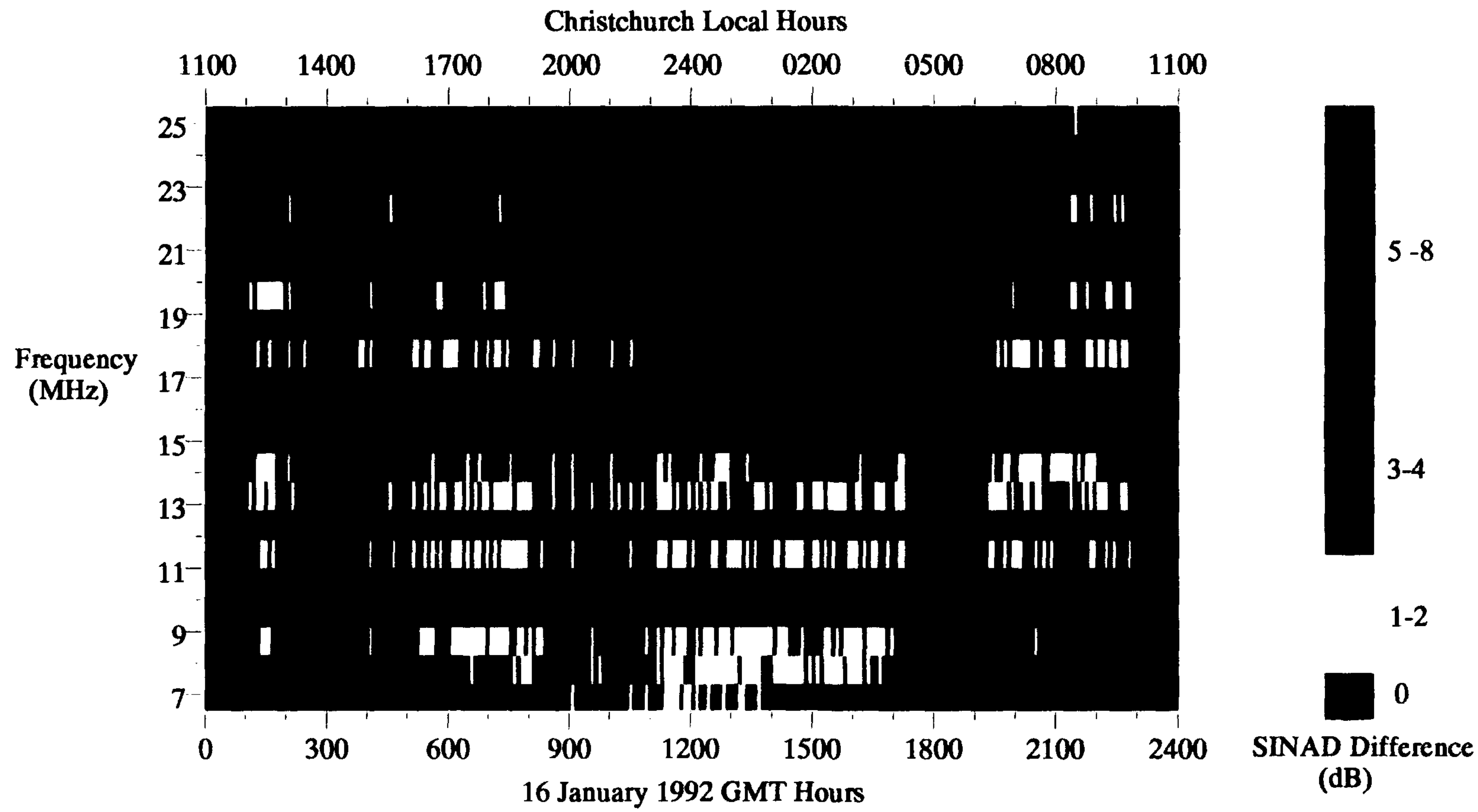

Figure A-59. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 16 January 1992

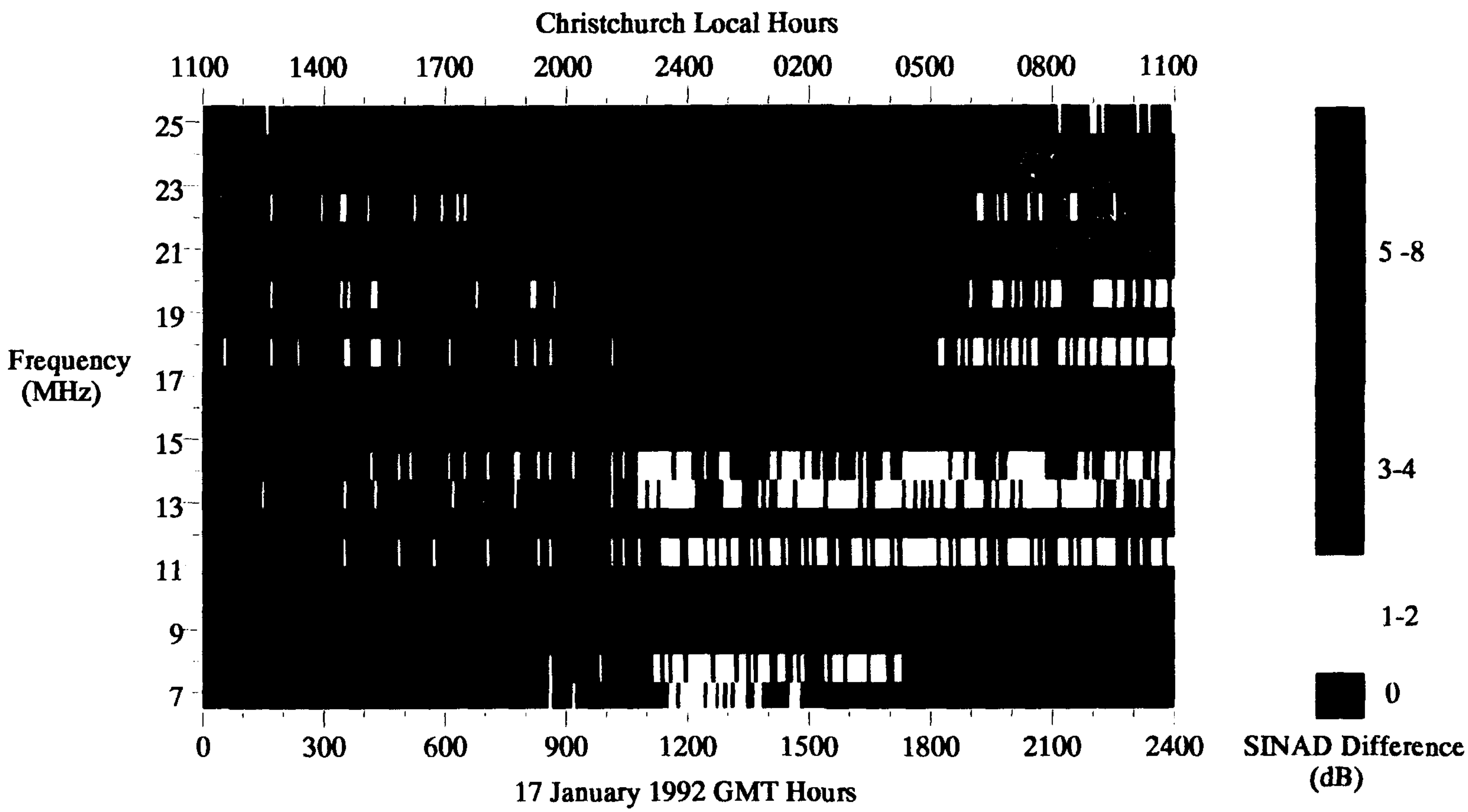

Figure A-60. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 17 January 1992

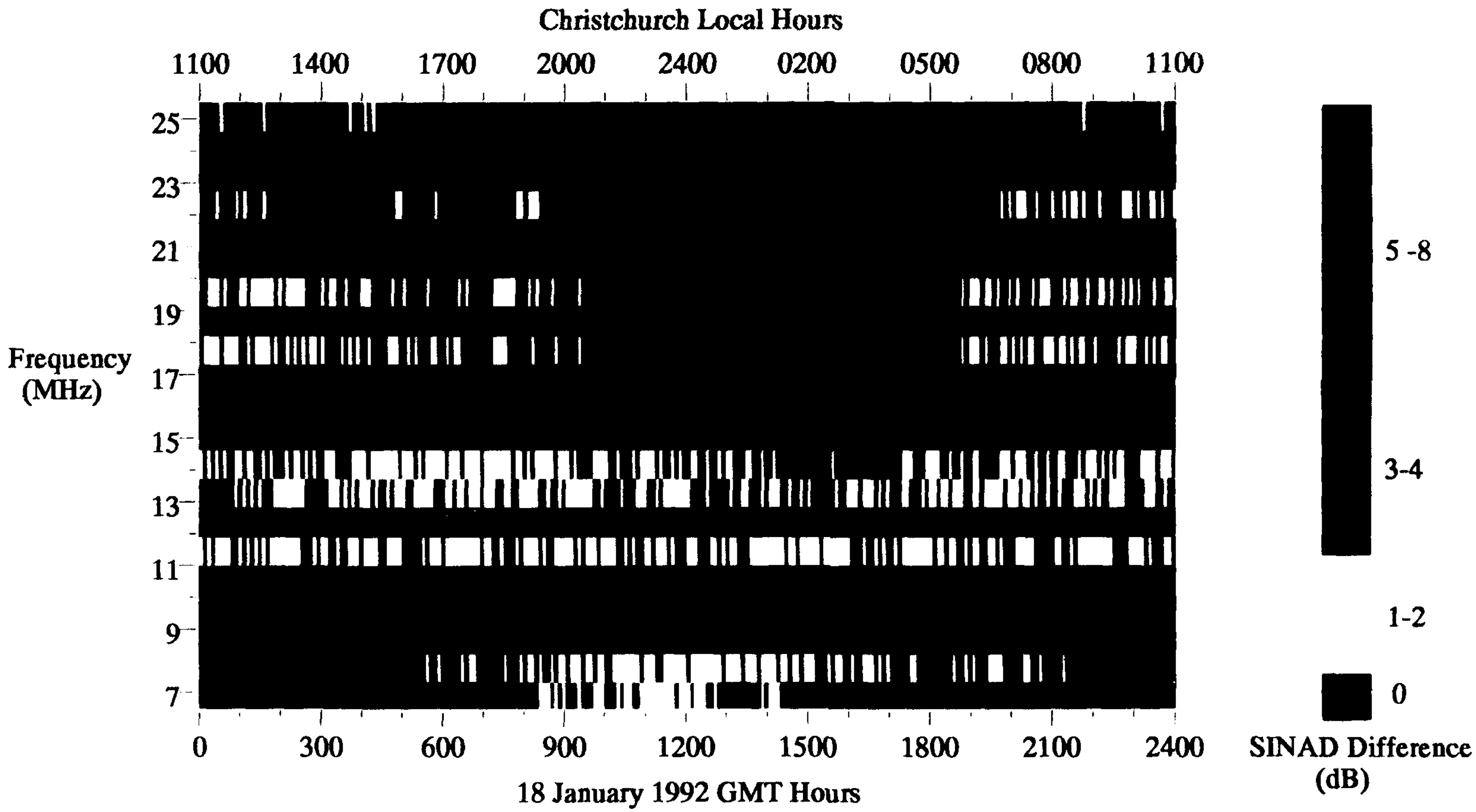

Figure A-61. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 18 January 1992

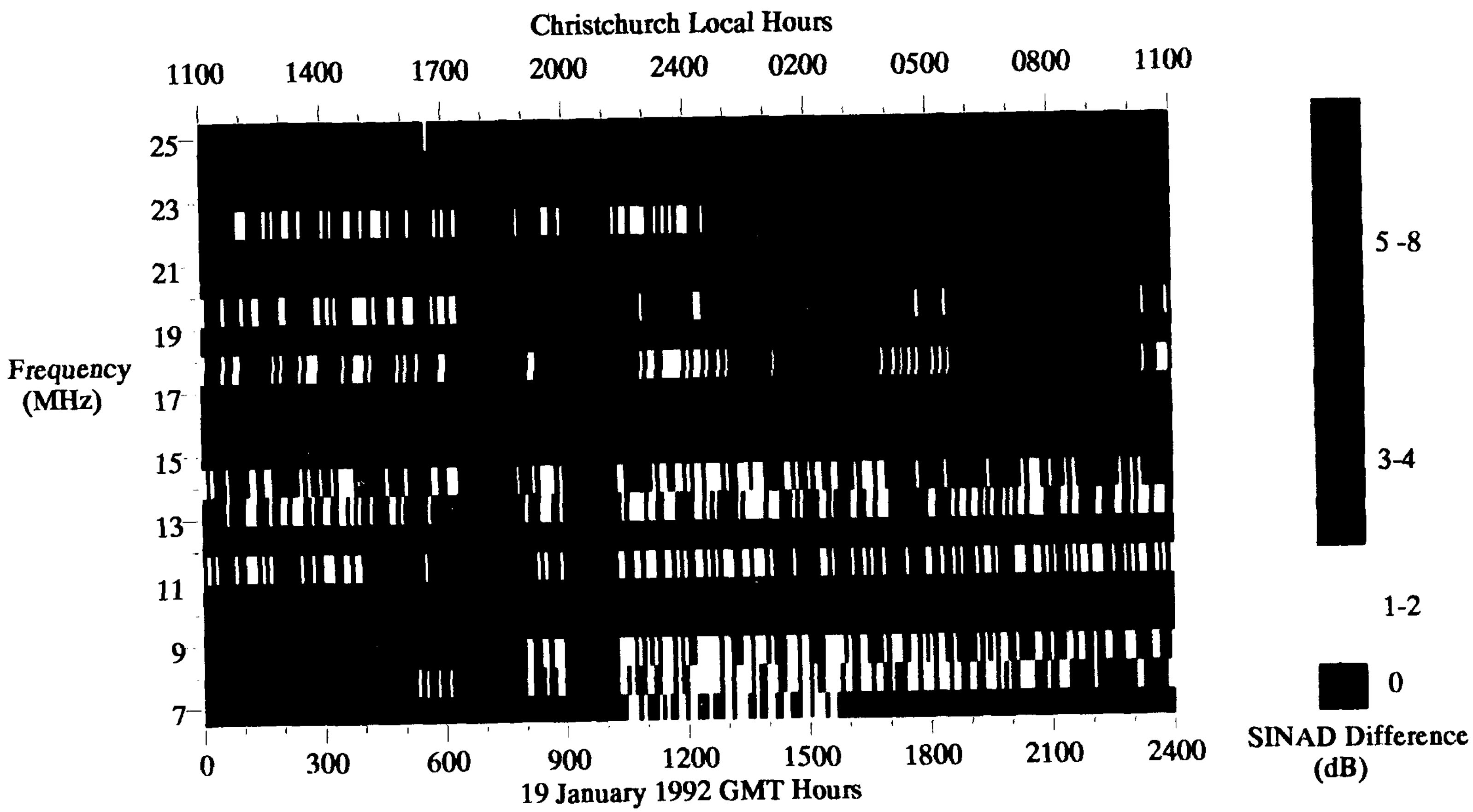

Figure A-62. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 19 January 1992

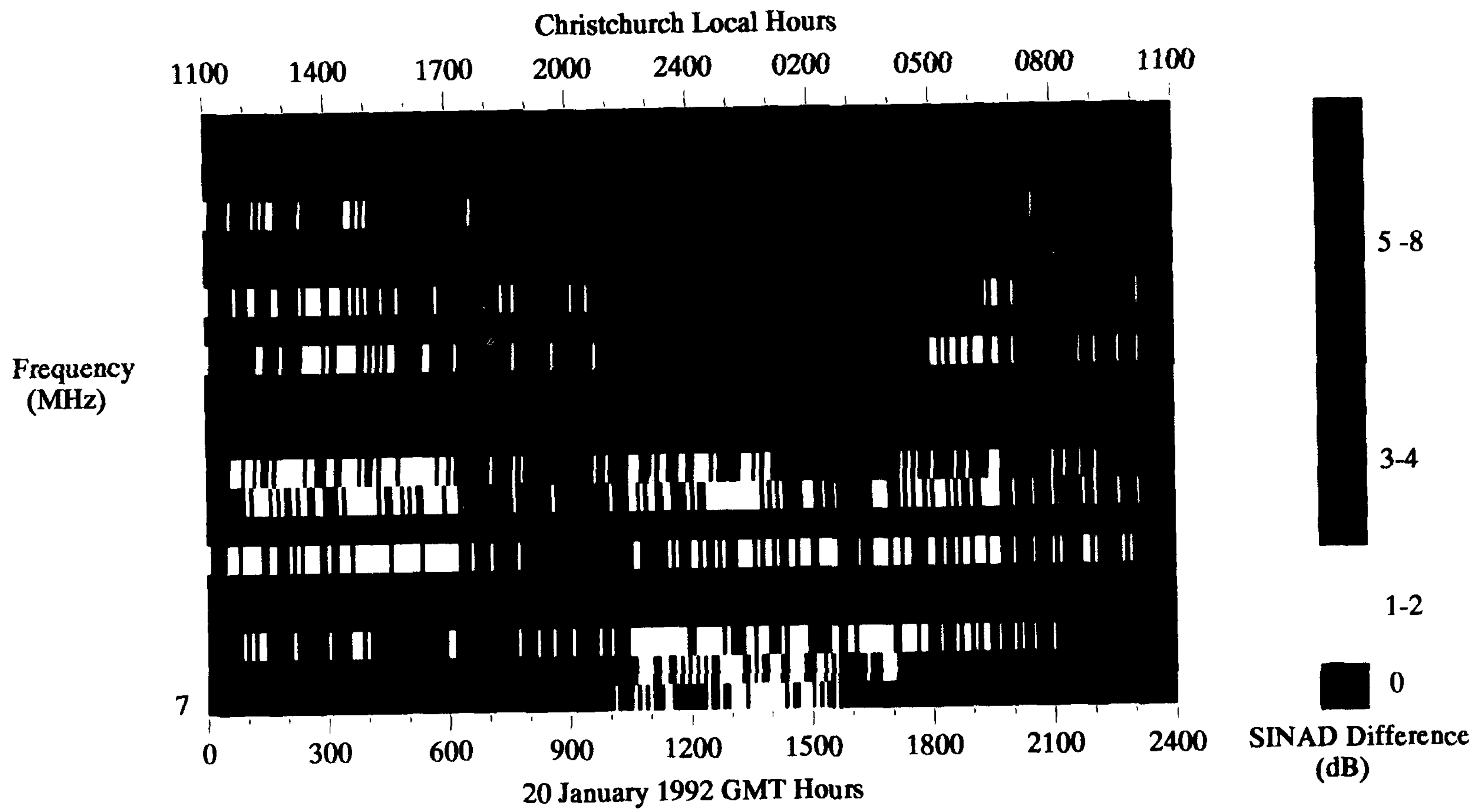

Figure A-63. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 20 January 1992

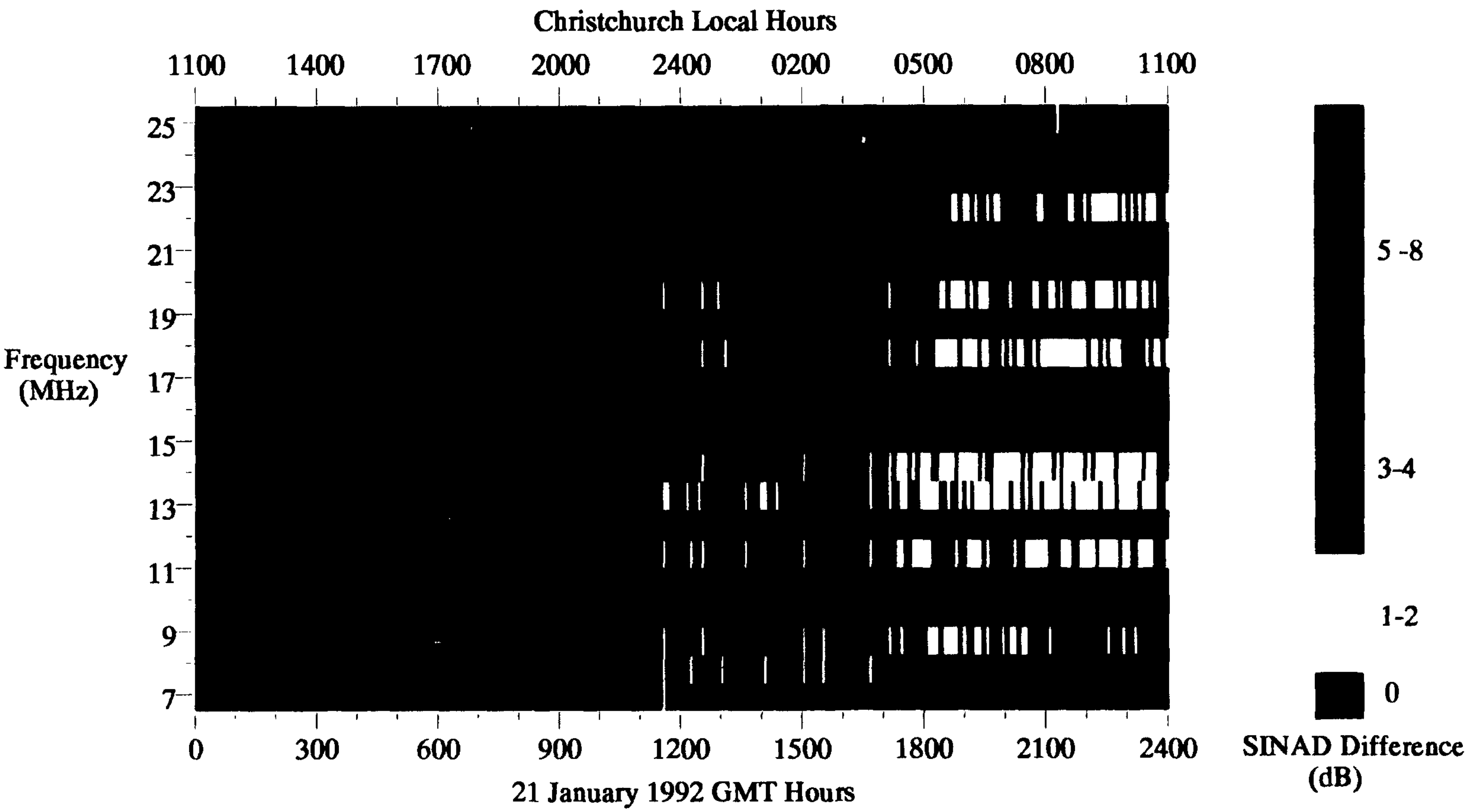

Figure A-64. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 21 January 1992

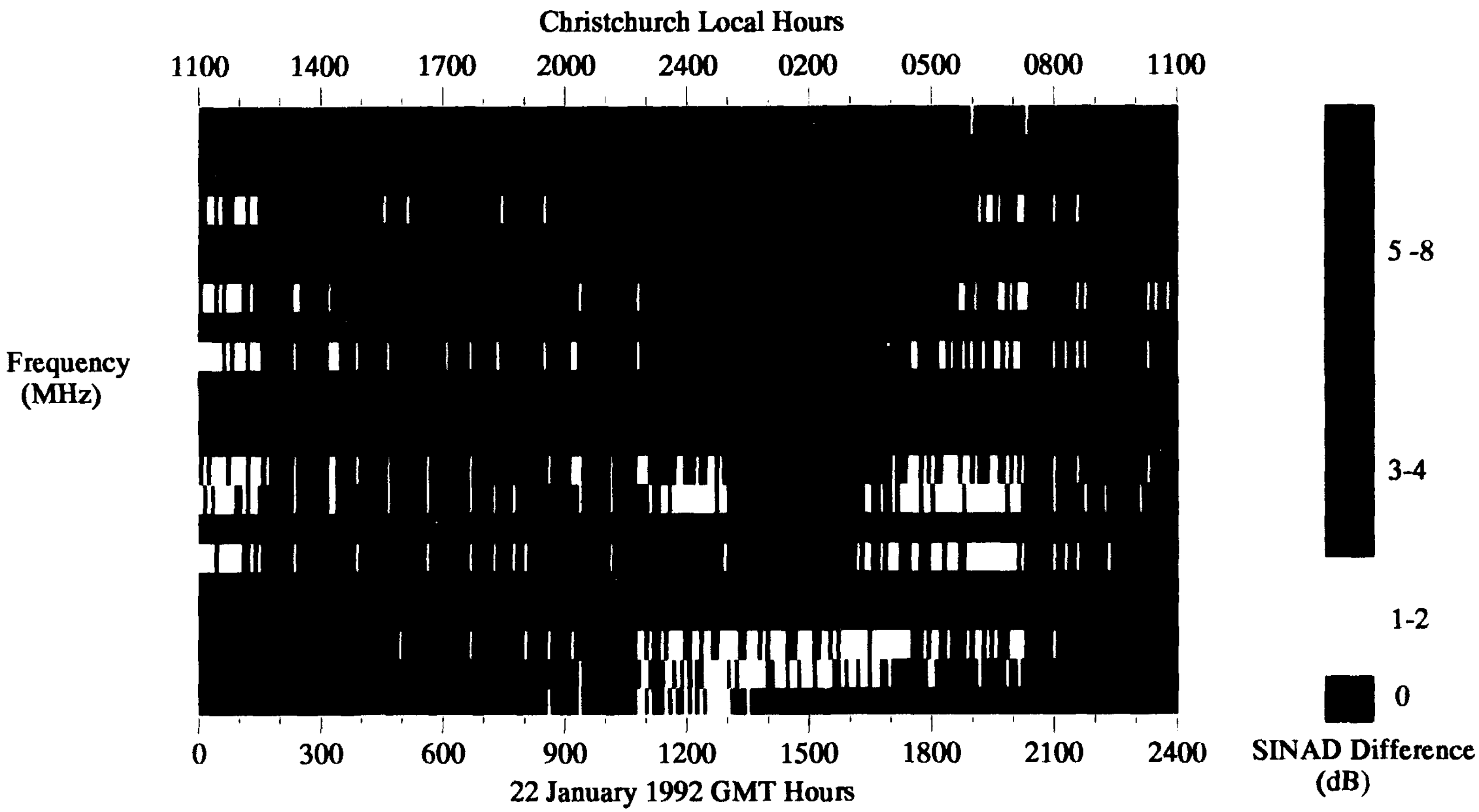

Figure A-65. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 22 January 1992

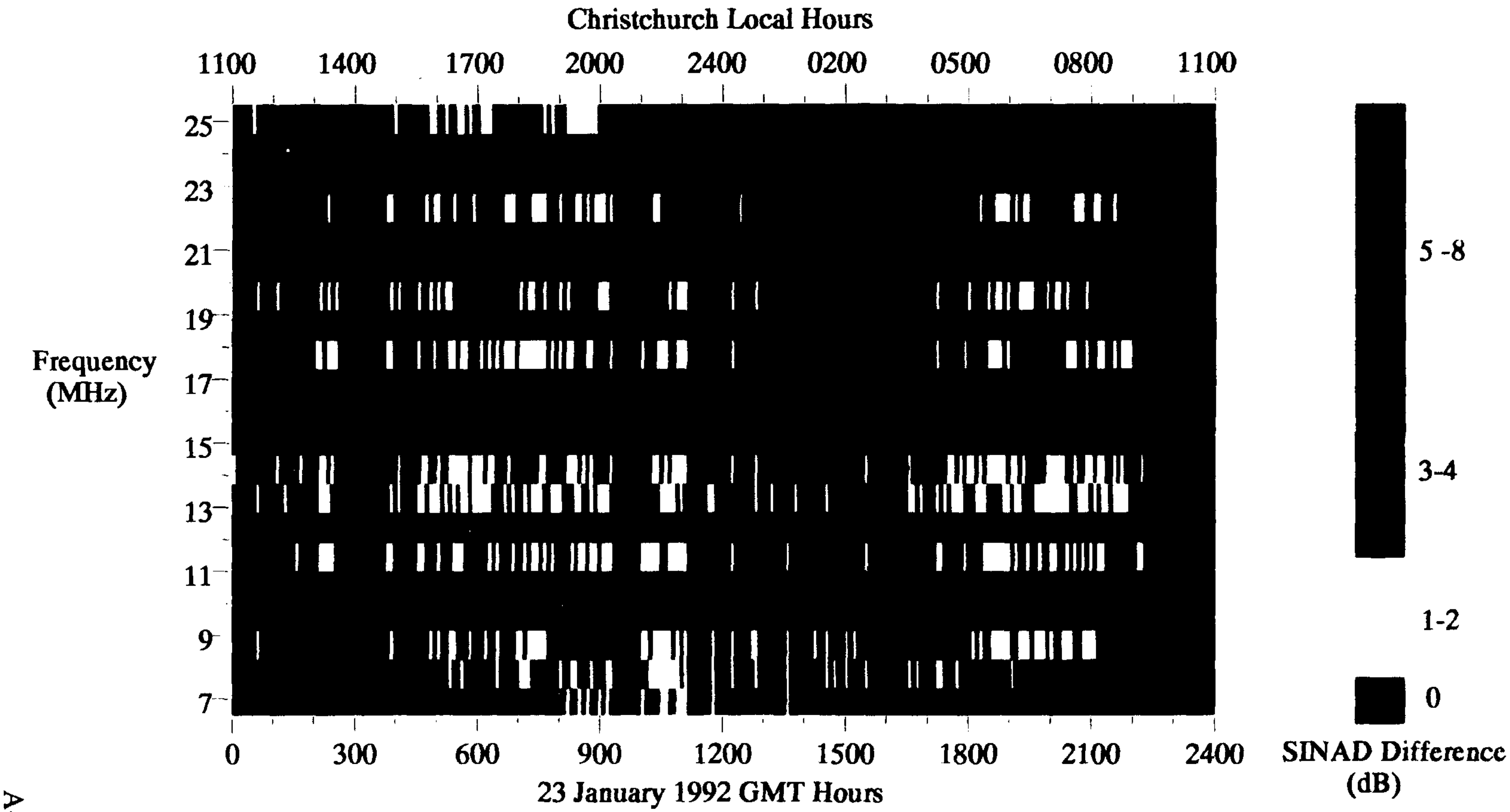

Figure A-66. Difference In Measured SINAD at Christchurch, NZ, and Black Island, Antarctica, 23 January 1992

APPENDIX B

NEC ANALYSIS OF SLOPING VEE ANTENNA

The sloping vee antenna was modeled using the software program Numerical Electromagnetics Code (NEC) version NEC-2 (reference 3). The antenna was modeled as three wires connected in a triangle with two 300 Ω load resisters connected at the endpoints of the two active elements. The layout of the antenna in Cartesian coordinates, as input in the program, is presented in figure B-1. The command file used to model the sloping vee antenna is listed below.

```
$ ON ERROR THEN GOTO WRAPUP
$ ASSIGN/PROCESS NEC.LST FOR$PRINT
$ NEC2
CM   SLOPING VEE ANTENNA
CM
CE
GW   1    40    0.00    0.00    50.00   95.67   227.50   15.00   0.20
GW   1    40    0.00    0.00    50.00   -95.67  227.50   15.00   0.20
GW   3    40    95.67   227.50  15.00   -95.67  227.50   15.00   0.20
GS   0    0     0.3048
GE
GN   0    0     0       0       3.0     0.0001
LD   4    3     1       1       300
LD   4    3     40      40      300
FR   0    21    0       0       5.0     1.0
EX   0    1     1       1       1.00    0.00    50.0
PT   -1   1     1       1       1       1
RP   0    1     181     1500    -90.00  90.00   1.00     1.00
EN
$ WRAPUP:
$DEASSIGN/PROCESS FOR$PRINT
```

The ground was modeled as a finite ground plane with a relative dielectric constant of three and a conductivity of 0.0001 mhos/meter which are CCIR (reference 5) values for very dry ground. The antenna was also modeled with ground constants of 30 and 0.01 mhos/meter which are the CCIR values for wet ground. This data is not presented but the pattern gains averaged about 2 dB higher than with dry ground. The dry ground pattern gains can be considered a worse case condition. Vertical pattern gain plots obtained from this NEC analysis are presented in plots B-2 to B-22.

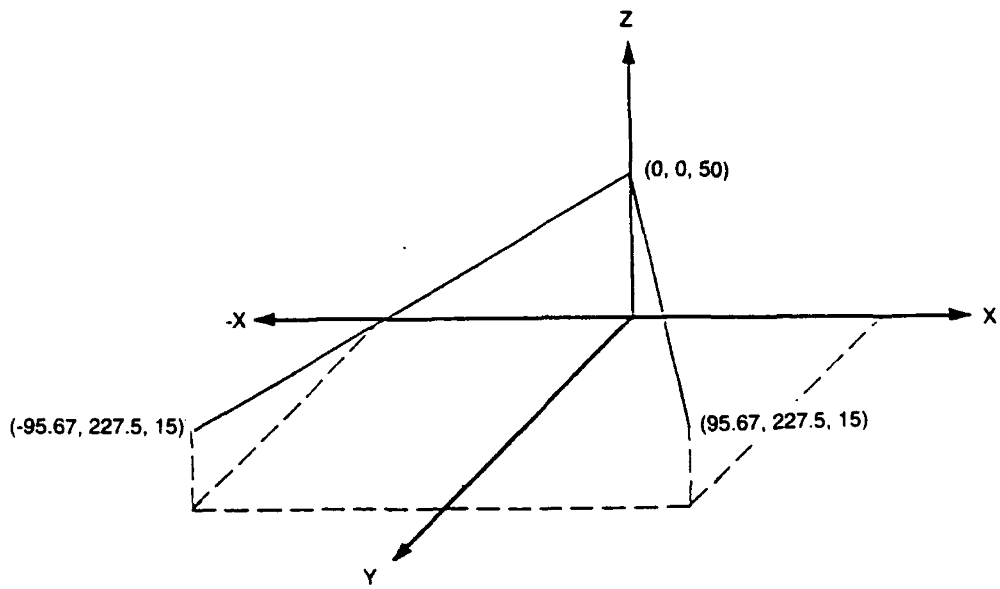

Figure B-1. Cartesian Coordinate Layout of Sloping Vee Antenna for NEC Analysis

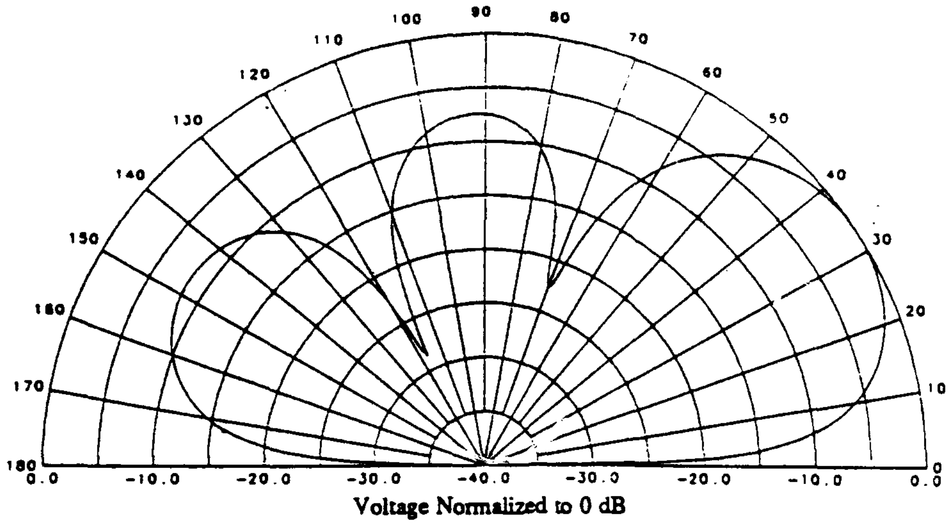

Figure B-2. Sloping Vee Antenna Vertical Pattern Gain, 5 MHz, Max Gain = -0.47 dBi

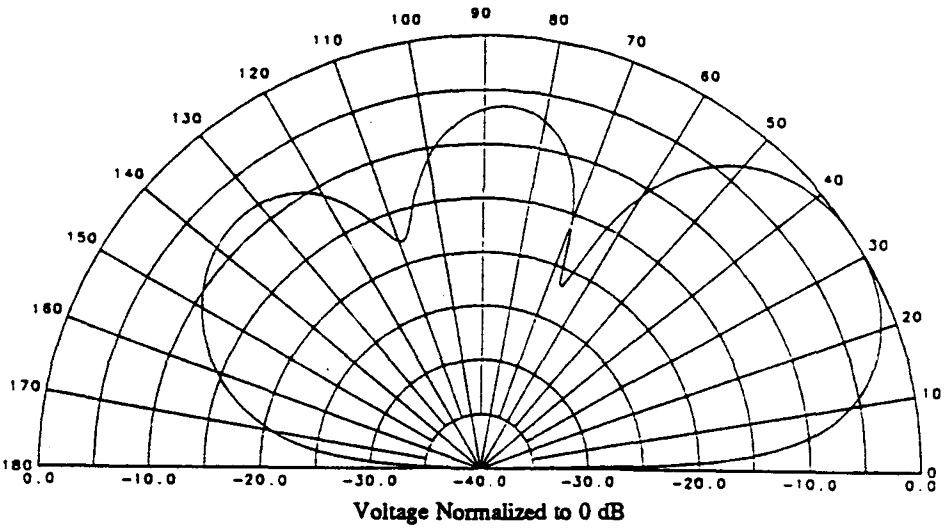

Figure B-3. Sloping Vee Antenna Vertical Pattern Gain, 6 MHz, Max Gain = 1.36 dBi

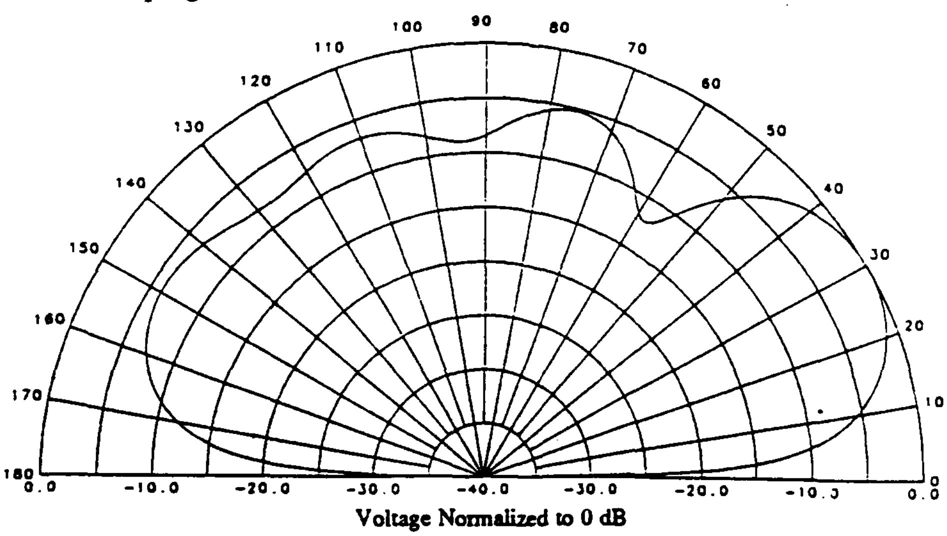

Figure B-4. Sloping Vee Antenna Vertical Pattern Gain, 7 MHz, Max Gain = 4.25 dBi

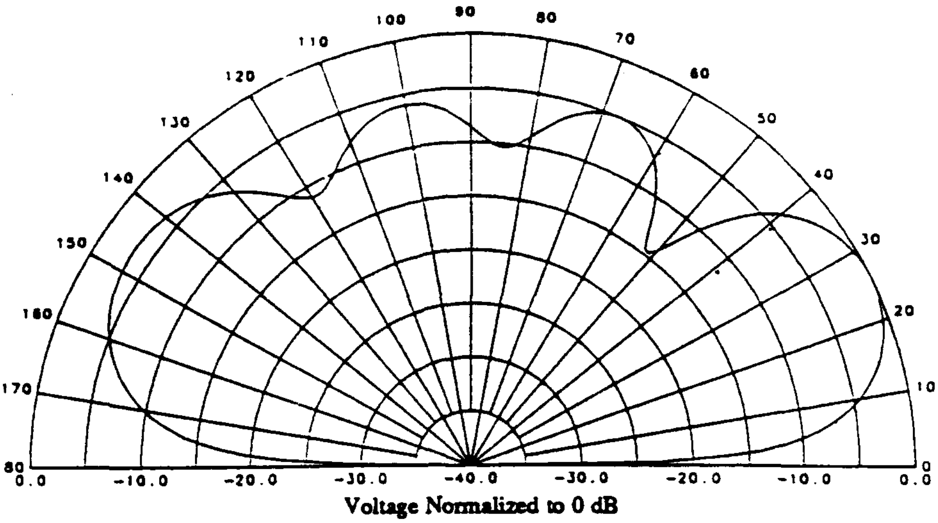

Figure B-5. Sloping Vee Antenna Vertical Pattern Gain, 8 MHz, Max Gain = 6.15 dBi

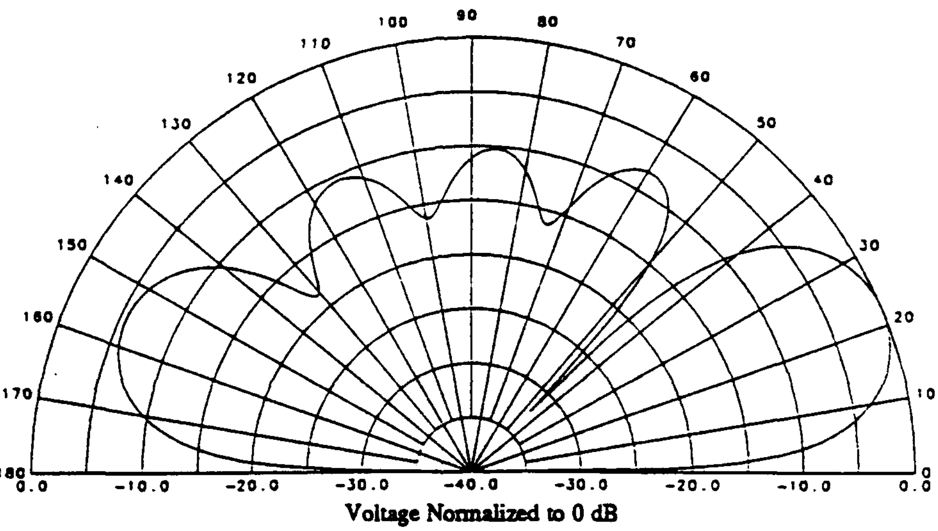

Figure B-6. Sloping Vee Antenna Vertical Pattern Gain, 9 MHz, Max Gain = 5.83 dBi

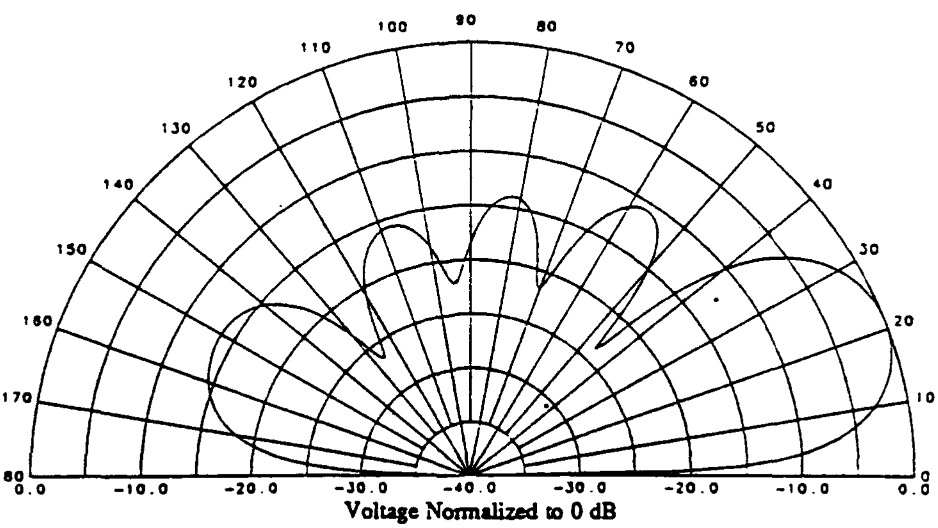

Figure B-7. Sloping Vee Antenna Vertical Pattern Gain, 10 MHz, Max Gain = 5.86 dBi

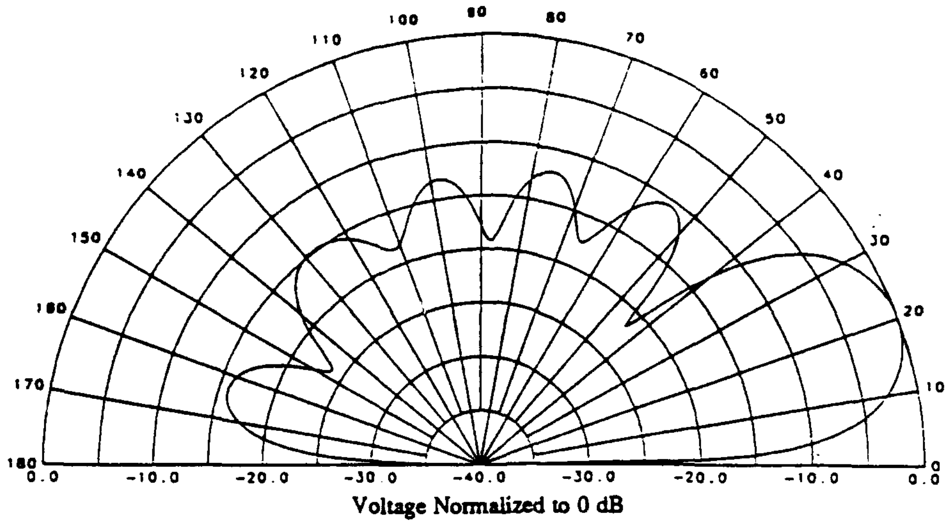

Figure B-8. Sloping Vee Antenna Vertical Pattern Gain, 11 MHz, Max Gain = 6.93 dBi

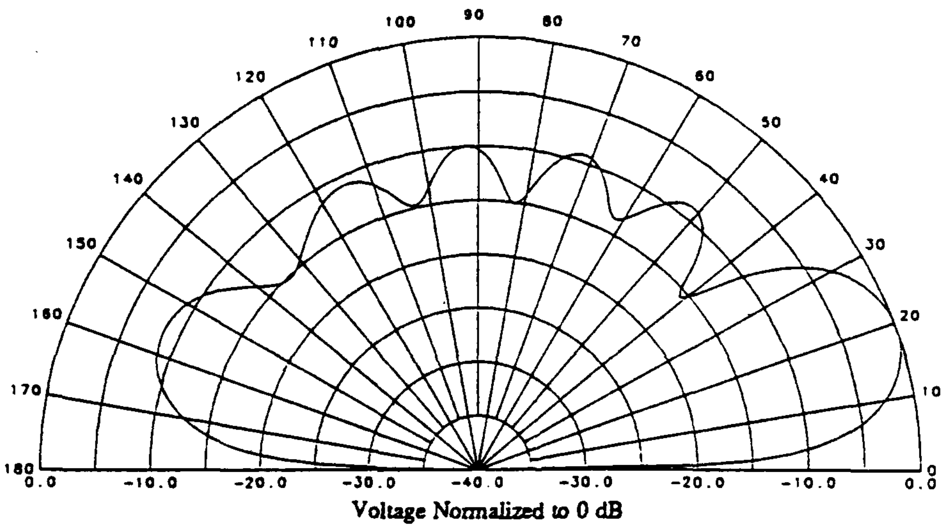

Figure B-9. Sloping Vee Antenna Vertical Pattern Gain, 12 MHz, Max Gain = 8.20 dBi

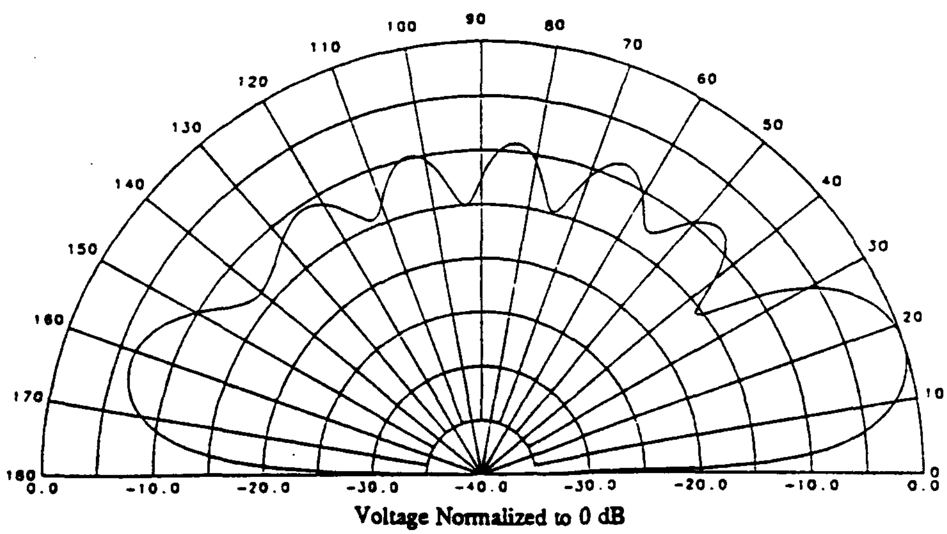

Figure B-10. Sloping Vee Antenna Vertical Pattern Gain, 13 MHz, Max Gain = 9.36 dBi

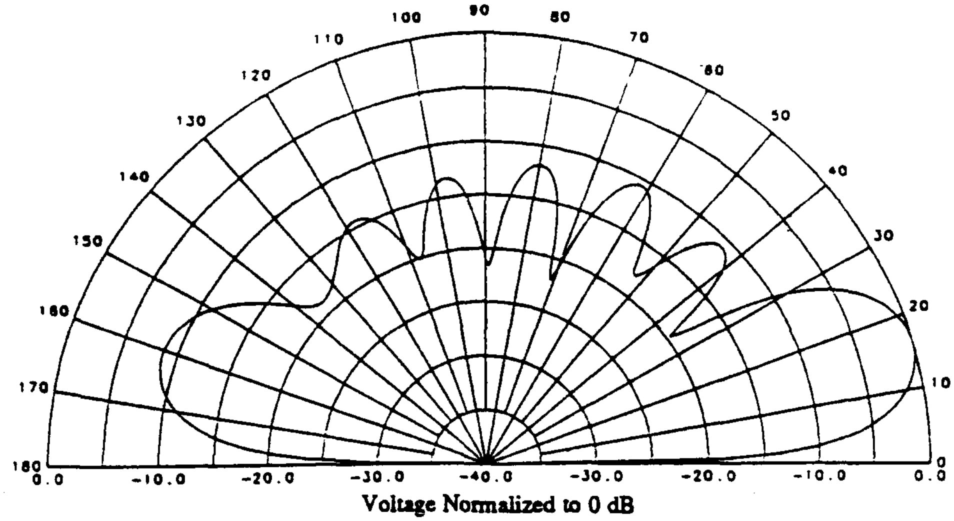

Figure B-11. Sloping Vee Antenna Vertical Pattern Gain, 14 MHz, Max Gain = 8.98 dBi

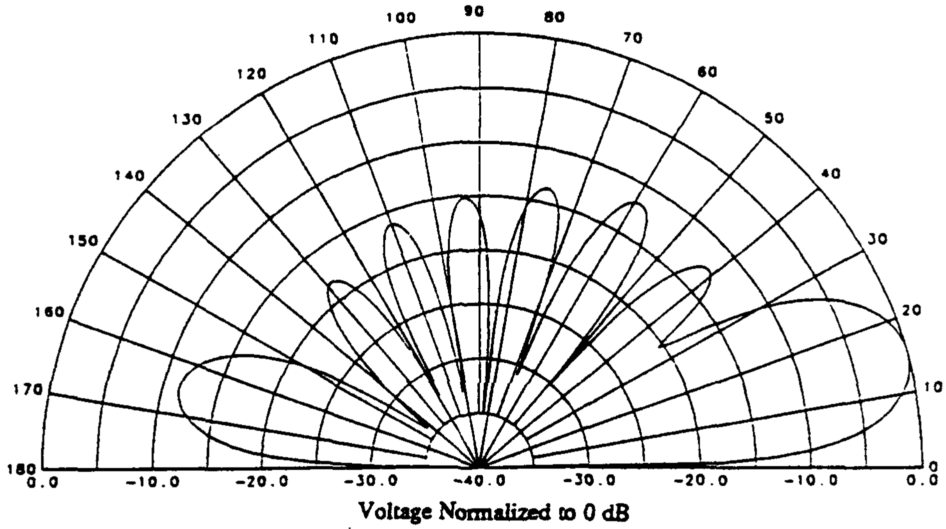

Figure B-12. Sloping Vee Antenna Vertical Pattern Gain, 15 MHz, Max Gain = 9.26 dBi

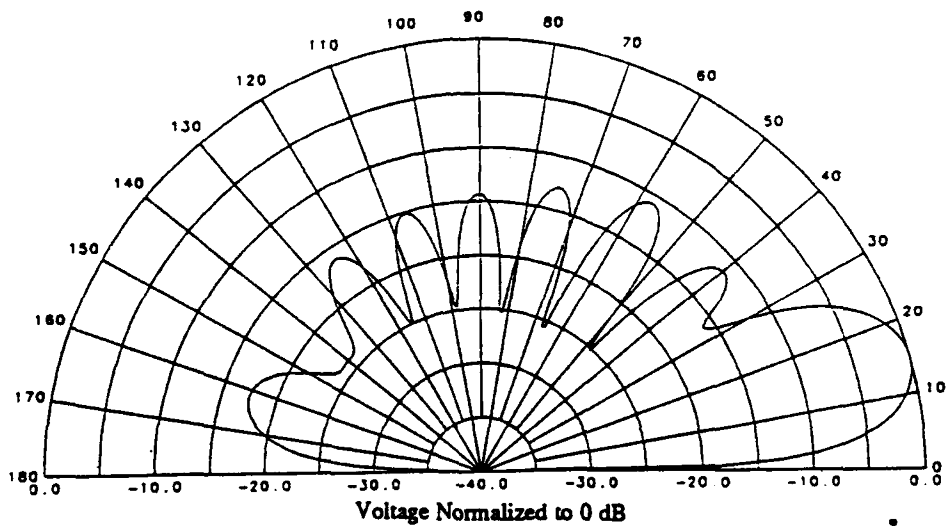

Figure B-13. Sloping Vee Antenna Vertical Pattern Gain, 16 MHz, Max Gain = 9.64 dBi

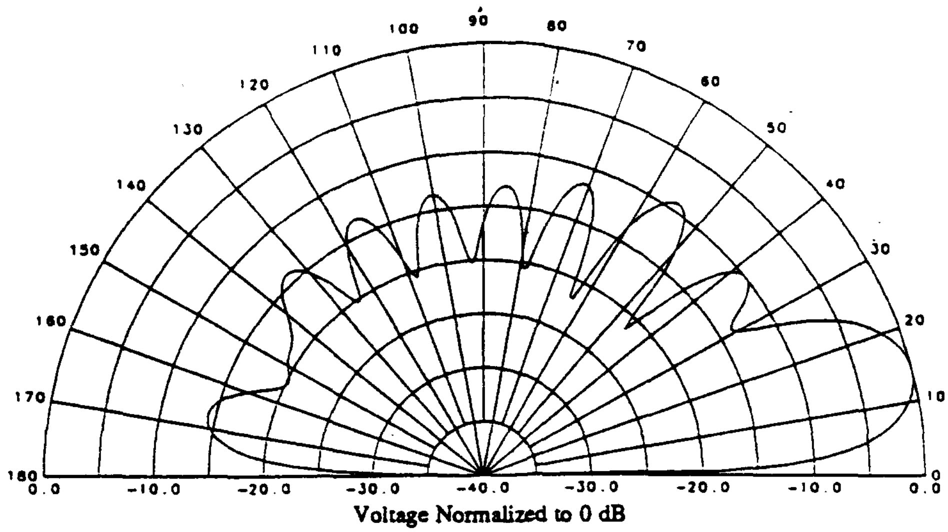

Figure B-14. Sloping Vee Antenna Vertical Pattern Gain, 17 MHz, Max Gain = 10.37 dBi

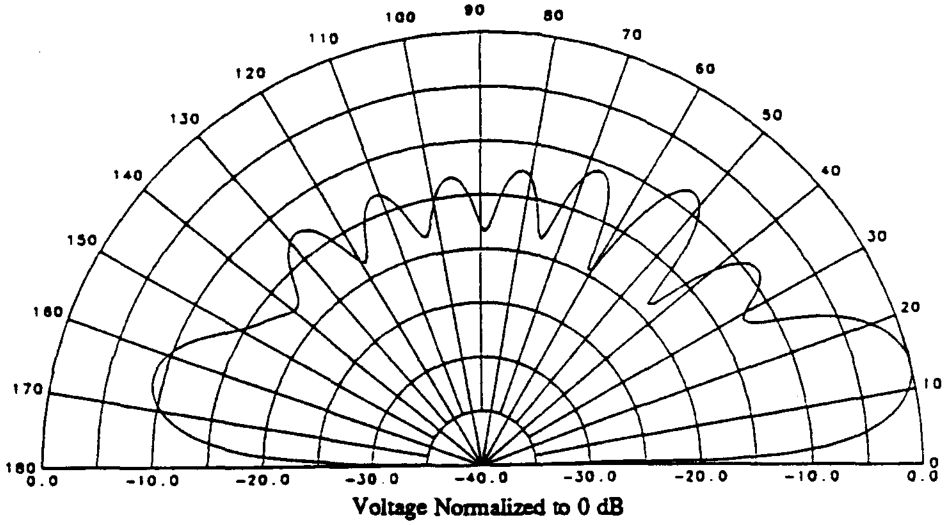

Figure B-15. Sloping Vee Antenna Vertical Pattern Gain, 18 MHz, Max Gain = 10.77 dBi

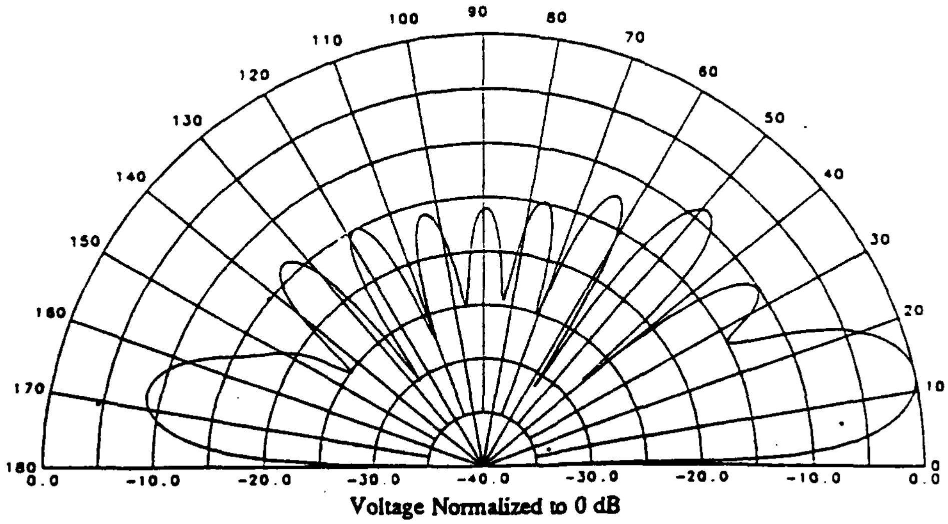

Figure B-16. Sloping Vee Antenna Vertical Pattern Gain, 19 MHz, Max Gain = 10.72 dBi

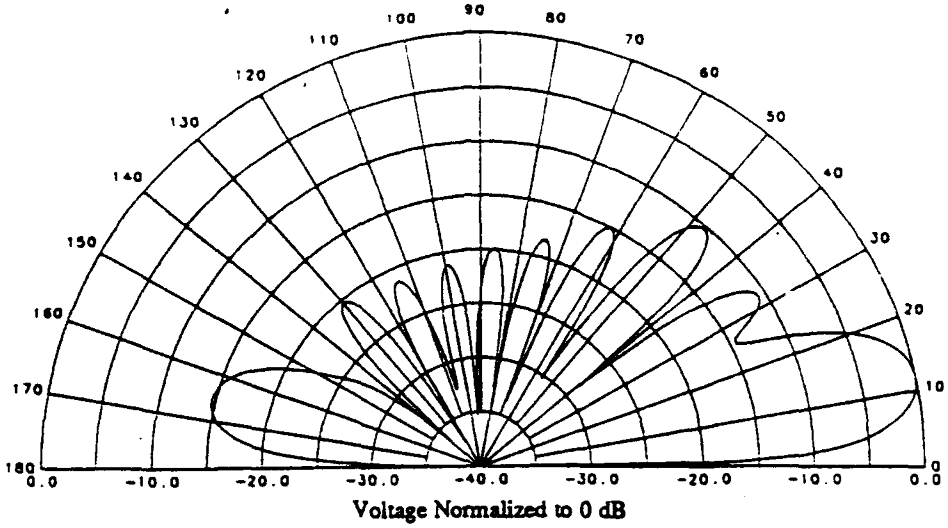

Figure B-17. Sloping Vee Antenna Vertical Pattern Gain, 20 MHz, Max Gain = 10.58 dBi

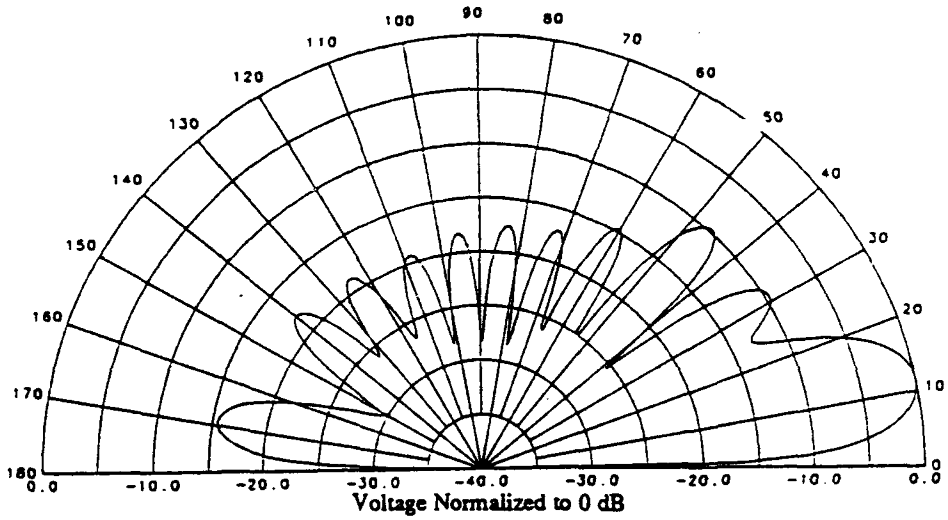

Figure B-18. Sloping Vee Antenna Vertical Pattern Gain, 21 MHz, Max Gain = 10.84 dBi

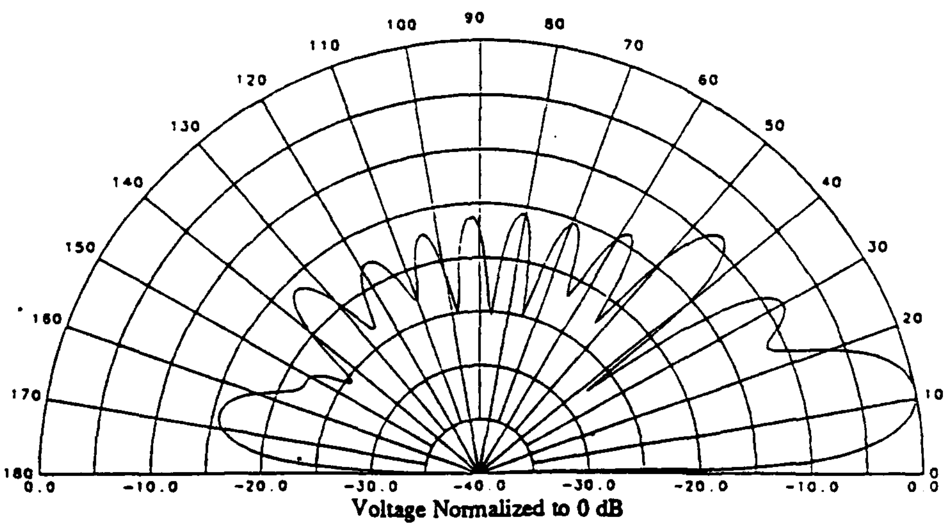

Figure B-19. Sloping Vee Antenna Vertical Pattern Gain, 22 MHz, Max Gain = 11.12 dBi

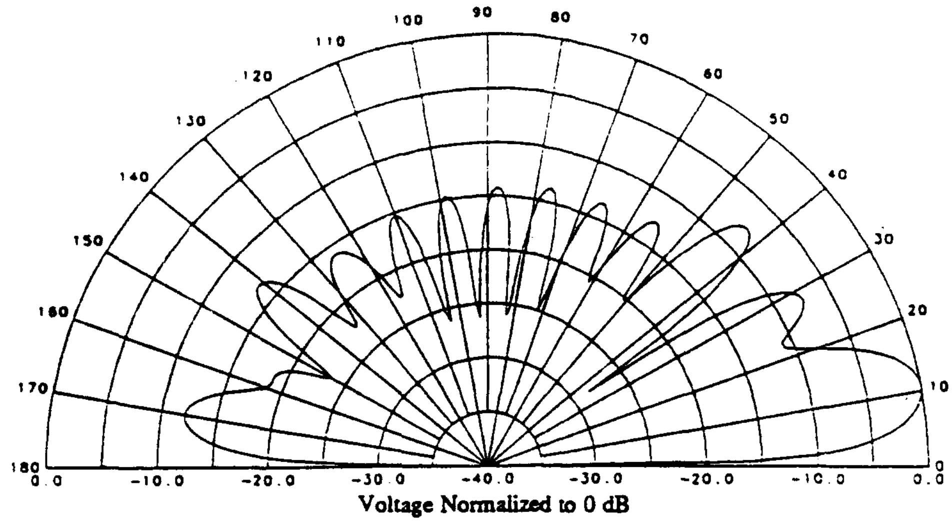

Figure B-20. Sloping Vee Antenna Vertical Pattern Gain, 23 MHz, Max Gain = 11.25 dBi

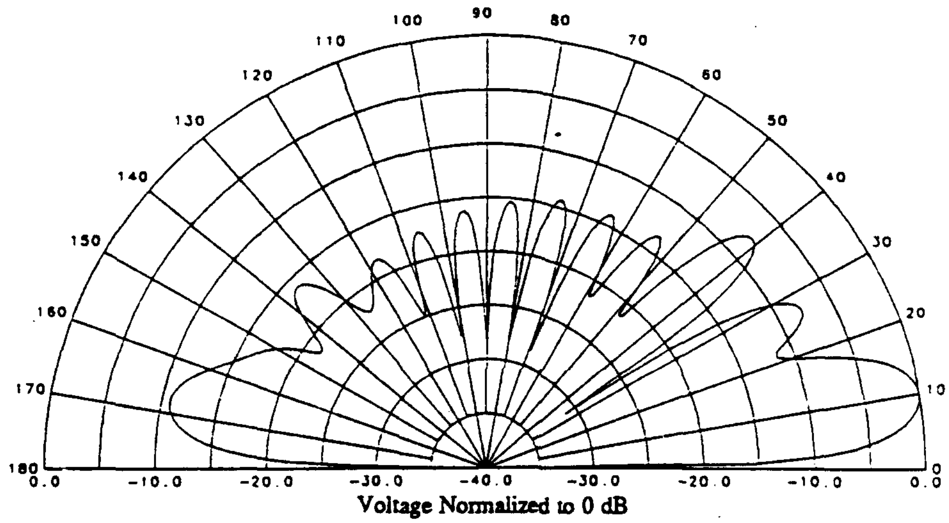

Figure B-21. Sloping Vee Antenna Vertical Pattern Gain, 24 MHz, Max Gain = 10.97 dBi

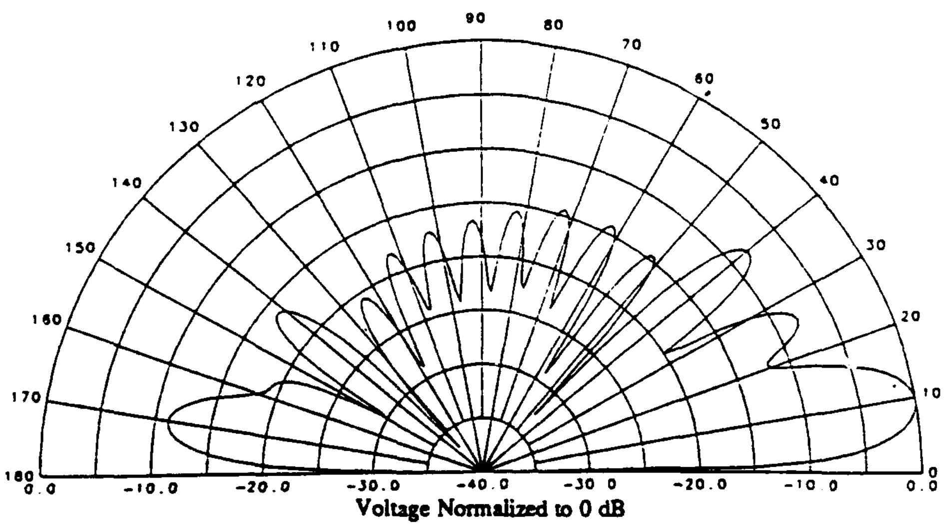

Figure B-22. Sloping Vee Antenna Vertical Pattern Gain, 25 MHz, Max Gain = 10.65 dBi

REFERENCES

1. Inospheric Communications Analysis and Prediction Program (IONCAP), NTIA/ITS Draft Report, September 1988.

2. ASAPS.

3. FED-STD-1045, Telecommunications: HF Radio Automatic Link Establishment, General Services Administration, Office of Information Resources Management, 24 January 1990.

4. MIL-STD-188-141A, Interoperability and Performance Standards for Medium and High Frequency Radio Equipment, Naval Pub. Office, 5801 Tabor Ave., Phil. PA, 19120, September 1988.

5. Numerical Electromagnetics Code (NEC) - Method Of Moments, Version NEC-2, Naval Ocean Systems Center TD 116, September1980.

6. Data From The High Frequency/Automatic Link Establishment (HF/ALE) Propagation Test In Antarctica, NUWC TM No. 931031, January 1993.

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